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ASD-TDR-63-585
VOLUME II

MECHANICAL PROPERTIES OF WROUGHT TUNGSTEN

TECHNICAL DOCUMENTARY REPORT No. ASD-TDR-63-585, VOL. II

NOVEMBER 1963

AF MATERIALS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Project No. 7381, Task No. 738103

(Prepared under Contract No. AF 33(616)-7385 by
The Marquardt Corporation, Van Nuys, California;
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NOTICES

600 - January 1964 - 162-22-390

FOREWORD

This report was prepared by the Materials Research and Development Laboratory of the Materials and Processes Section of The Marquardt Corporation, Van Nuys, California, under USAF Contract No. AF33(616)-7385. The contract was initiated under Project No. 7381, "Materials Applications", Task No. 738103, "Data Collection and Correlation". All work was administered under the direction of the AF Materials Laboratory, Research and Technology Division, with Mr. C. L. Harmsworth as project engineer. The program was conducted under subcontract from the Hughes Tool Company, Culver City, California.

This report covers work performed between April 1962 and April 1963.

ABSTRACT

Tensile and creep properties to 5000°F were determined for wrought unalloyed tungsten sheet in order to establish design criteria. Three lots of material, prepared in accordance to the same specification, were used.

Hardness and tensile values below 2500°F could be correlated for entire lots of material. Correlation was found at strain rate and hold time versus tensile strength properties or elongation values, at certain temperatures.

Properties varied with powder lot to such an extent as to affect design parameters.

This technical documentary report has been reviewed and is approved.

D. A. Shinn, Chief
Materials Information Branch
Materials Application Division
AF Materials Laboratory

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I. INTRODUCTION

In April of 1962, The Marquardt Corporation subcontracted from The Hughes Tool Company to perform the final phases of Contract AF33(616)-7385, "Design Properties of Wrought Tungsten (Elevated Temperature Mechanical Testing). The work was conducted by the Materials Research and Development Laboratory of the Materials and Process Section. The objective and technical phases of the program have been abstracted from ASD-TDR-63-585, Volume I, and are presented below for the purpose of supplying background information.

"The principal objective of this program is to determine the mechanical properties of commercially available unalloyed tungsten and develop a compilation of representative data that can be used by the designer for very high temperature applications."

"The first phase of this program is to establish a material specification that will insure a high quality level....

The second phase will determine the effect on properties of material produced to the resulting specification by five (5) producers of tungsten products....

The third phase will determine the effect of four (4) basic production methods on bar stock....

The fourth phase will determine the effect on sheet of three (3) types of fabrication methods....

The fifth phase will determine the properties of the material under the following conditions: Eight (8) temperatures (room temperature, 2000°F and 500°F increments to 5000°F); Two (2) hold times of 30 seconds and 20 minutes; and a strain rate of 0.1 in/in/sec throughout the test, or of 0.001 in/in/sec to yield strength followed by 0.01 in/in/sec to ultimate strength....

The sixth phase will consist of creep tests. Four stresses will be used to cause two percent creep in times of about 30 seconds, one minute, 20 minutes, and one hour at eight (8) temperatures in 500°F increments from 1500°F to 5000°F."

Marquardt contracted to perform the work specifically described in the fifth and sixth phases of the program with some modifications and additions. The original objective of the program was not changed; however, in order to secure optimum data, slight modifications in the technical procedures were made. These changes were requested prior to the initiation of the work and involved such parameters as hold time, creep time, and test temperatures.

Manuscript released by authors August 1963 for publication as an ASD Technical Documentary Report.

A. OBJECTIVES

Marquardt's objectives for this portion of the complete program were:

To fabricate test specimens from three powder lots of 0.050 inch thick pure tungsten sheet.

To conduct creep rupture tests from 1500 to 5000°F to determine the stresses required to reach 2% plastic creep in 30, 120, 600, and 3600 seconds.

To conduct tensile tests from 70°F to 5000°F using four different test conditions. These test conditions used various combinations of hold times and strain rates.

Conduct hardness and chemical compositions checks on the (three powder lots) sheet material supplied.

II. EXPERIMENTAL TECHNIQUE

A. MATERIAL

The tungsten sheet used in this program was ordered by the Hughes Tool Company to their Material Specification HMS6-1006, Commercially Pure Tungsten Sheet, dated October 1961. A copy of this specification appears in Appendix A of this report. The referenced specification was written during the first phases of this program and the development work relating to this specification can be found in ASD-TDR-63-585, Vol. I (Reference 1). The material was ordered to a minimum Rockwell hardness of (45-N) 50.0. This value was a deviation from the specification requirement of (45-N) 46.0. Work at Hughes had shown that increased hardness resulted in better room temperature strength and elongation values.

A great deal of emphasis had been placed on the development of a material specification and checking of material from many vendors. The tungsten sheet used in this program (fifth and sixth phases of the over-all program) can be considered to be among the best obtainable at the time of purchase (ordered October 1961, delivered March 1962) because of this preliminary work.

All tungsten sheet was supplied by Fansteel Metallurgical Corporation. The material was prepared from three identically processed powder lots. There were 38 sheets in Lot A, 35 sheets in Lot B, and 35 sheets in Lot C. All sheets had the following dimensions: 11 inches long, 3 inches wide, and 0.050 inches thick. Visual inspection disclosed that some sheets had severe laminations and surface defects. Test specimens prepared from these sheets were carefully checked to insure the absence of any defects which would influence the accuracy of the results. (E. g., no specimen was tested which had a defect in the reduced section; however, several specimens did contain defects in the grip portion). Each lot of tungsten was chemically analyzed. The test specimens were identified to conform to the identification procedure used in the first phases of this program, ASD-TDR-63-585 (Reference 1).

However, it should be noted that specimens designated "BA", "BB", "BC" in this report were not prepared from the same material noted in Reference 1. The specimen identification procedure used at Marquardt is given below:

Lot	Specimen Number
A	BA-1 through BA-178
B	BB-1 through BB-167
C	BC-1 through BC-169

B A 1

1 — Specimen number

A — Lot designation (three (3) lots from producer)

B — Producer (Fansteel)

B. TEST SPECIMENS

1. Geometry

A rectangular test specimen design (i.e., no reduced section) was employed during the initial phases of this program by Hughes Tool Company. However, in attempting to continue with this same configuration, some difficulties were encountered. Preliminary tests on 1/2 x 11 inch rectangular tungsten specimens at temperatures of 2500°F to 5000°F disclosed the following problems:

a. Overheating of the copper friction grip assemblies.

b. Excessive oxidation of the specimen in the area outside the atmosphere chamber.

From these findings, the decision was made to machine the center 2-1/2 inch section of the specimen to one-half the sample width. This concentrated the heating to the center section, minimized the temperature gradient and gave more accurate results for the procedures employed. The concentration of heating eliminated failures from oxidation of that part of the specimen outside the atmosphere chamber.

2. Fabrication

All specimens were machined by Marquardt's Manufacturing Department to the configuration shown in Figure 1. After machining, the specimens were dye penetrant checked for laminations and cracking. About 2% were rejected because of excessive cracks. Specimens having minute cracks located outside the reduced section were accepted. Light passes on a belt sander removed surface and edge irregularities and oxidation. The surface preparation described resulted in the following advantages:

a. Accuracy of hardness measurements were increased.

b. Thermocouple attachment was facilitated.

c. Data scatter was reduced.

C. TEST EQUIPMENT

1. Marquardt Elevated Temperature Test Machine (TM-1)

This machine was developed by The Marquardt Corporation to evaluate the mechanical properties of materials from cryogenic temperatures, to their melting points. The test machine is hydraulically loaded and has a capacity of 50,000 pounds in tension or compression. Tests are generally run by controlling strain or load rate. A built-in programmer maintains positive rate control continuously and automatically. The programmer is fed by electrical feedback signals from the extensometer (strain rate control) or the load cell (load rate control) depending upon which control method is being used. The testing speed may be varied at any time during the test.

Strain measurements are made with a separable, differential transformer type extensometer which is clipped directly to the test portion of the specimen. Special high temperature gripping tips are used. The extensometer is water cooled. The extensometer remains in place until the specimen ruptures and a complete tensile stress-strain curve is obtained for each tensile test. These curves are automatically plotted on a high response Moseley Autograf X-Y recorder.

Test temperatures in excess of 5000°F and heating rates in excess of 200°F/second were attained by using self-resistance heating. The source of the heating current was a 10 KVA cycle step-down transformer. Heating current to the specimen was automatically controlled by a Variac, which in turn was controlled by the output of thermocouples attached to the test specimen.

Constant improvement in both the physical machine and procedural methods have provided Marquardt with a sophisticated piece of elevated temperature mechanical test equipment that can provide information no other equipment can duplicate.

Because of the combination of high test temperatures and low load required, certain modifications to the TM-1 were necessary. These were:

a. The use of aluminum (vs. steel) spacer blocks to reduce the inertia of the ram system when tensile loading starts.

b. The complete redesigning of the tailstock of the TM-1 to reduce friction by installing linear bearings.

c. Support rails utilizing roller bearings were designed and installed to eliminate any tendency for the load cell to rotate.

d. To insure smooth operation, at the low loads expected, a new threaded attachment for the load cell and a new collar for thermal expansion "take up" were made. In addition, all threaded components were hand lapped.

Special friction grips were designed, fabricated, and tested. In addition to gripping the test coupons to apply the tensile load, friction grips must also transmit high amperage current to heat the specimen to the required test temperature. The friction grips were therefore fabricated from copper because of its low electrical resistivity, high thermal conductivity, and high ductility. High ductility was necessary to insure that the gripping force would tend to deform the copper blocks rather than shatter the tungsten strip. Numerous tests were run to determine necessary grip engagement length to prevent pullout or slippage, minimum engagement for electrical conduction across the tungsten specimen and optimum and uniform bolting torque to apply a uniform gripping force. Various shim thicknesses were also investigated.

D. TEST PROCEDURES

1. Hardness

Initial hardness readings obtained using the Rockwell 45-N scale were not consistent, due to surface variations. The Rockwell A scale gave more consistent values because of its deeper indentation.

Rockwell A hardness measurements were taken on each test specimen after machining. The measurements were taken on a belt sanded surface of the grip area approximately one-half inch from the reduced area.

2. Creep Rupture Tests

A static loading system was incorporated on the TM-1 machine for conducting the high temperature (low load) creep-rupture testing. Dead weight loading was used and the force transmitted by pulley and cable directly to the specimen grips. At the start of each test a hydraulic system was used to apply the load at a consistent rate.

The specimens were resistance heated to the required test temperature at 200°F/seconds, the same rate used for tensile tests. The specimens were held at temperature for one minute to insure stabilization. The required stress was applied rapidly, within 1-2 seconds, in order to avoid variable or excessive deformation during the loading period. The creep deformation (strain) was recorded from the moment that the required stress level was reached. Strain was measured with the extensometer attached directly to the test portion of the specimen as in the tensile tests. The creep vs. time curves were automatically recorded on a Wheelco single channel strip chart recorder calibrated to read 0.100 inch full scale, with the smallest increment being 0.001 inch.

The Hughes Tool Company requested that four stress levels be used for each temperature and powder lot to be tested. Specifically "---- One of the four creep stress levels shall be the 0.2% offset yield stress taken from the short-time tensile stress-strain curves. Based on prior tests, it is expected that this stress will cause 2% creep in approximately ten minutes. The remaining three creep stress levels shall be chosen by the seller such that 2% creep will occur in approximately 0.5, 2.0, and 60 minutes." After several exploratory tests, Marquardt found that creep testing at the yield strength gave 2% creep in 10 minutes at only a few temperatures. It was assumed that the emphasis was meant to be on obtaining 2% creep in 10 minutes, not in testing at the yield strength. For the remainder of the creep testing, the yield strength requirement was disregarded and testing to obtain 2% creep in 10 minutes was substituted for this specific requirement.

3. Tensile Tests

Each lot of material was tensile tested using four different sets of test conditions. These conditions were:

Test Condition	Strain Rate (in/min)		Hold Time (minutes)	
	To Yield	To Rupture	1000-2000°F Tensile Tests	2500-5000°F Tensile Tests
1	0.005	0.05	5	3
2	0.05	0.5	5	3
3	0.005	0.05	30	30
4	0.05	0.5	30	30

The tensile specimens tested at elevated temperatures were heated by electrical self-resistance at a controlled rate of 200°F/second.

The TM-1 programmer was activated at the completion of the hold time. The feedback system held the desired strain rate and the specimen was stressed to the yield strength. The strain rate was then increased by a factor of ten and the loading was continued until the specimen failed.

4. Temperature Measurements

Temperature measurements from 1500 to 3000°F were taken using Platinum-6% Rhodium vs. Platinum-30% Rhodium thermocouples (Baker Platinum, Div. Englehard Industries). Tungsten vs. Tungsten-26% Rhenium (Hoskins Manufacturing Company) thermocouples were used for temperatures of 3500°F to 5000°F. A Leeds and Northrup millivolt potentiometer was used to read both types of thermocouples.

Initially, two thermocouples were attached to the reduced portion of each test specimen. After runs at various test temperatures it was apparent that temperatures could be held within approximately ± 1% along the gage length with the specimen configuration being used. Thereafter, only one thermocouple was used.

Initially, there was no thermocouple calibration for Tungsten vs. Tungsten-26% Rhenium at 4500 and 5000°F. Based on extrapolation and past experience, values of 40.68 millivolts at 4500°F and 43.0 at 5000°F were used. Recent data published by Hoskins Manufacturing Company closely agree with these values.

5. Protective Atmosphere

The TM-1 Atmosphere Enclosure and an atmosphere of 93% Argon-7% Hydrogen were used for all elevated temperature tensile and creep rupture tests. Complete coverage of the reduced area of the test specimen is afforded by this chamber which has been utilized many times on other programs.

III RESULTS

A. HARDNESS

The Rockwell A hardness values for each specimen used in this program are listed in Tables I through III.

B. CREEP

The stress vs. time creep-rupture curves for powder Lots A, B, and C, for temperatures of 1500°F to 5000°F, are presented in Figures 2 through 9, 10 through 17, and 18 through 25 respectively. The data are listed in Tables IV through XI, XII through XIX, and XX through XXVII, respectively.

On a stress vs. time basis, the 2% creep lines for each test temperature have been plotted on one graph for each powder lot. Figures 26 through 28 present these graphs for Powder Lots A, B, and C, respectively.

Composite graphs and a table were made up to show the stress required to reach 2% creep in 30, 120, 600, and 3600 seconds for each powder lot. Each graph includes this data for all test temperatures (1500-5000°F). Figures 29 through 31 contain these composite graphs for Powder Lots A, B, and C, respectively. Table XXVIII contains the data used to develop these figures.

Figures 32 and 33 were prepared to compare creep properties of the three powder lots. Figure 32 shows 2% creep in 30 seconds at temperatures from 1500 to 5000°F. Figure 33 shows 2% creep in 3600 seconds at temperatures from 1500 to 5000°F.

C. TENSILE TESTS

The results of the Room Temperature to 5000°F tensile tests for Test Condition 1, Powder Lots A, B, and C are reported in Tables XXIX through XXXIV. Similar results for Test Condition 2 are reported in Tables XXXV through XXXIX. Results for Test Condition 3 are presented in Table XXXX through XXXXII. Results for Test Condition 4 are presented in Tables XXXXIII through XXXXV.

D. CHEMICAL COMPOSITION

Samples from all three powder lots were analyzed for oxygen, hydrogen, carbon, and nitrogen and thirty-four (34) other elements. The results are presented in Table XXXXVI.

IV DISCUSSION

A. HARDNESS

1. Hardness

The hardness values for Powder Lots A and C were similar, with the majority of values from both lots falling between Rockwell A 73.0 and 74.0. Powder Lot B had a slightly higher hardness, with most values between 74.0 and 75.0.

2. Hardness versus Tensile

In addition to higher hardness values, Powder Lot B also had higher ultimate and yield strength values than Lots A and C for test temperatures of 2000°F and below. If there were a true correlation between hardness and tensile values, it would be operative only at temperatures below the recrystallization temperature of the metal. For tungsten, the recrystallization temperature is between 2500 and 3000°F. There appears to be a valid correlation between hardness and tensile values at test temperatures of 2000°F and below.

B. CREEP TESTS

All creep lines plotted were determined using the most conservative points. This was particularly justified because of the slight cooling experienced at the extreme ends of the two-inch gage length.

In Figure 32, presenting stress to reach 2% creep in 30 seconds, all three powder lots had similar properties up to 3500°F. Above 3500°F, Powder Lot B is inferior to either A or C.

In Figure 32, presenting stress to reach 2% creep in 3600 seconds, from 1500 to 3000°F Powder Lot A is slightly inferior to B or C, which are almost equal. From 3500 to 5000°F, Lot B is inferior to A or C, which are almost equal.

The creep properties obtained from these identical powder lots also show behavior not normal to identical heats. All powder lots had similar creep-rupture properties from 1500°F to 3000°F although B was slightly superior at 1500°F. At 3500°F and above, the creep-rupture properties of Lot B fall well below those of Lot C or A which are about equal.

C. TENSILE TESTS

1. Tensile Tests - Effect of Strain Rate on Strength and Elongation

a. Strength

A detailed statistical study was not made, however, certain trends were apparent. For Lots B and C, the higher strain rates (for Y.S. 0.05 in/min. vs. 0.005 in/min.; for U.T.S. 0.5 in/min. vs. 0.05 in/min.) gave higher values for most test temperatures from R.T. to 5000°F. This increase varied from 1 to 40 percent.

For Lot A, the higher strain rates gave higher Y.S. and U.T.S. values for most test temperatures of 2000°F and above. For temperatures below 3500°F there were some cases in which the slower strain rates gave higher values or resulted in no change.

b. Elongation

Strain rate changes the elongation values of wrought tungsten only at temperatures in excess of 3000°F. In 71% of all tests above 3000°F, where strain rate was increased by a factor of ten, increases in total elongation of up to 7% (elongation %) were noted. This behavior was noted in all powder lots.

2. Tensile Tests - Effect of Hold Time on Strength and Elongation

a. Strength

For each powder lot, data for comparison of tensile and yield strength vs. hold time were available only at test temperatures of 2000, 2500, 3000 and 3500°F. The hold times investigated were:

Hold Time (Min.)	Test Temperatures °F
3	2500 - 3500°
5	2000
30	2000 - 3500°

At 3000 and 3500°F, the 30 minute hold time tests had no apparent effect on ultimate tensile and yield strengths. At 2000°F, the 5 minute hold time tests gave ultimate and yield values of 0 -38% greater than the 30 minute hold time tests. At 2500°F, a 3 minute hold time gave yield strength values 100% greater than tests with a 30 minute hold time, ultimate tensile strength values for the 3 minute hold times were up to 50% greater.

The modest decrease in ultimate tensile strength and yield strength at 2000°F is due to the material being stress relieved while under test. Those 2500°F samples, held for 30 minutes, exhibited a consequent large drop in strength values. This drop was caused by considerable recrystallization.

The large drops in tensile strength values between 2000°F and 2500°F, found for test conditions 1 through 4, are caused by a combination of two factors. These factors are the normal drop in strength accompanying increased test temperatures combined with the lowering in strength associated with recrystallization.

b. Elongation

Exposure for prolonged periods at temperature (30 minutes) did not affect elongation properties at 2000°F. However, at 2500 and 3000°F the 30 minute hold time appears to greatly increase total elongation values. In 83% of the tests conducted at 2500 and 3000°F, ductility increased with the 30 minute hold time. Elongation values doubled at 2500°F in several cases. Lesser increases occurred at 3000°F in all but one case.

3. Tensile Tests - Effect of Powder Lot on Strength and Elongation

a. Strength

From room temperature to 2000°F the ultimate and yield strengths of Powder Lot B were consistently higher than both Lots A and C for all test conditions. For all test conditions from 3000°F to 5000°F little difference was found to exist between the lots, although Powder Lot C had slightly higher values.

Data obtained from each test condition were examined for general trends. Approximate values are given below.

Test Condition 1

Below 2500°F Lot B is superior to Lot A in yield strength by 7-17% and tensile strength by 8-9%, it is superior to Lot C by 5-28% and 21% respectively. At 2500°F and above, Lot C is superior in yield strength to A by 17-95% and in ultimate tensile strength to Lot A by 16% and Lot B by 14%.

Test Condition 2

From room temperature through 2000°F, Lot B was superior to Lot A in tensile strength by 6-47% and yield strength by 5-30%. Lot B was also superior to Lot C in tensile strength by 16-37% and yield strength by 17-28%. At four of the six higher test temperatures (2500 to 5000°F) Lot C had the highest ultimate tensile and yield strengths.

Test Condition 3

At 2000°F Lot B had the highest tensile and yield strengths (12% higher than C and 19% higher than A). For the remaining three test temperatures, Lot C had slightly higher tensile strengths.

Test Condition 4

The results were similar to Test Condition 3, Lot B had higher ultimate tensile strengths at 2000°F than A or C by 36% and 7% and higher yield strengths by 35% and 13% respectively. For the remaining three temperatures, Lot C had generally higher ultimate tensile and yield strength properties in all cases.

b. Elongation

Powder Lot C exhibited zero elongation at room temperature whereas Lots A and C had 0.5 - 0.9%. At 1000°, 1500°, and 2000°F Lot C had slightly higher total elongation values than A or B, which were almost equal. Elongation at 2500°F (approximate recrystallization temperature) increased for all lots to approximately 1 to 3 1/2 times those obtained at 2000°F (below the recrystallization temperature). In the temperature range of 2500°F to 5000°F elongation values varied widely from lot to lot. At 2500 and 3000°F, Lot B generally has higher elongation than A or C. From 3500-5000°F, Lot A generally has highest elongation.

V CONCLUSIONS

A. HARDNESS

1. Hardness versus Tensile Strength

Hardness, tensile, and yield strengths can be correlated directly for entire powder lots below 2500°F.

B. CREEP

Creep-rupture properties were generally similar from lot to lot. But the creep-rupture properties of Powder Lot B at 3500°F and above were well below those of Lots A and C.

C. TENSILE TESTS

1. Tensile Tests - Effect of Strain Rate on Strength and Elongation

a. Strength

The higher strain rates generally gave higher tensile and yield strength values at all test temperatures for Powder Lots B and C. For Lot A, faster strain rates generally gave higher tensile values, at temperatures of 2000°F to 5000°F only.

b. Elongation

Below 3000°F increases in strain rate did not affect the elongation values. From 3000-5000°F, a noticeable increase in elongation values resulted from increases in strain rate.

2. Tensile Tests - Effect of Hold Time on Strength and Elongation

a. Strength

Higher tensile values were found at 2000 and 2500°F for short hold time (3 and 5 minutes vs. 30 minutes).

b. Elongation

Higher elongation values were found at the 2500 and 3000°F test temperatures for the longer hold time (30 minutes vs. 3 or 5 minutes). This effect of hold time did not exist for any other test temperatures.

3. Tensile Tests - Effect of Powder Lot on Strengths and Elongation

Although processed identically, all powder lots did not exhibit identical or even similar behavior in elevated temperature tensile testing. Experimental techniques and normal scatter in testing no doubt contributed to these variations, however, there exists certain trends which indicate a basic difference among powder lots. The first indication was in hardness values. Lots A and C exhibited definitely lower hardnesses than did Lot B. Secondly, the tensile strengths of Lots A and C are definitely lower than Lot B at temperatures of 2000°F and lower. This would indicate a valid correlation of tensile properties with hardness values at these temperatures and a definite difference between Lot B and Lots A and C.

Differences in elongation values between powder lots further strengthens the possibility that variations do exist in the basic makeup of the three powder lots and/or the processes involved in fabrication of the material.

VI RECOMMENDATIONS

Great care should be taken when designing and producing assemblies from wrought tungsten because of the variations that exist in different lots of material. Large variations can be expected when using material produced at different times or from different producers. Designing from mechanical properties developed for one or two powder lots and producing parts from other undocumented lots is particularly discouraged.

While this program indicated that the creep properties did not vary as much as tensile properties, variations were found in both that were large enough to affect design requirements. These variations were found even after great care had been taken in specification writing, vendor choice and in-plant quality assurance tests.

The scatter obtained indicates that the state of the art in the production of wrought tungsten, while advancing rapidly, is still in need of improvement to meet aerospace industry needs. Continuing work is needed on the determination of mechanical properties of wrought tungsten. More data are required in order to establish statistical values and confidence levels for use by designers. Additional data will also allow monitoring of the continuing improvement in the state of the art in the production of wrought tungsten. It is therefore recommended that a program be initiated to continue the work wrought tungsten. This program should include:

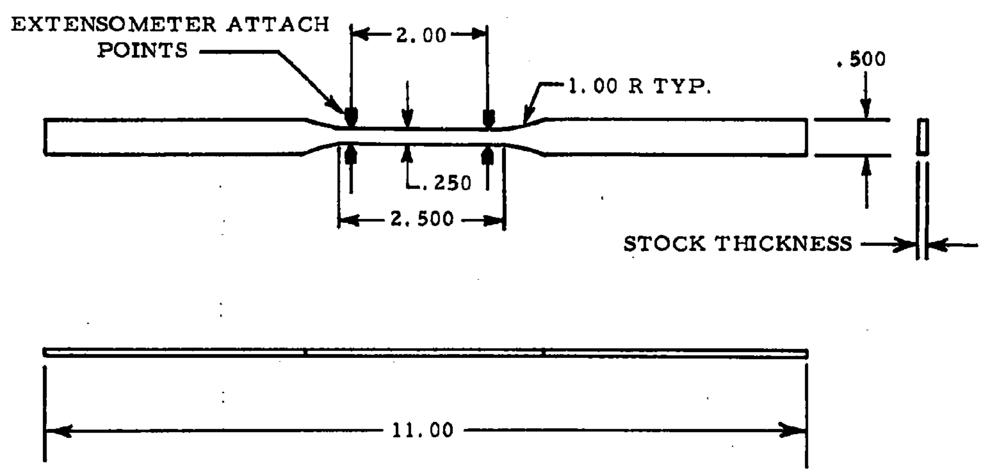
a. Tightening and modification of the tungsten specification with respect to mechanical properties.

b. Evaluation of tungsten material produced to meet the more stringent specification requirements.

c. Establishment of statistical confidence levels for tungsten mechanical properties for design purposes.

LIST OF REFERENCES

1. Leggett, H. and Parechanian, H. (Unclassified Title), Mechanical Properties of Wrought Tungsten, Volume I. WADC-TDR-63-585. Wright Air Development Center, Wright-Patterson Air Force Base, Ohio. July 1963. (Unclassified Report).



SCALE - HALF SIZE

FIGURE 1. FLAT TENSILE AND CREEP SPECIMEN

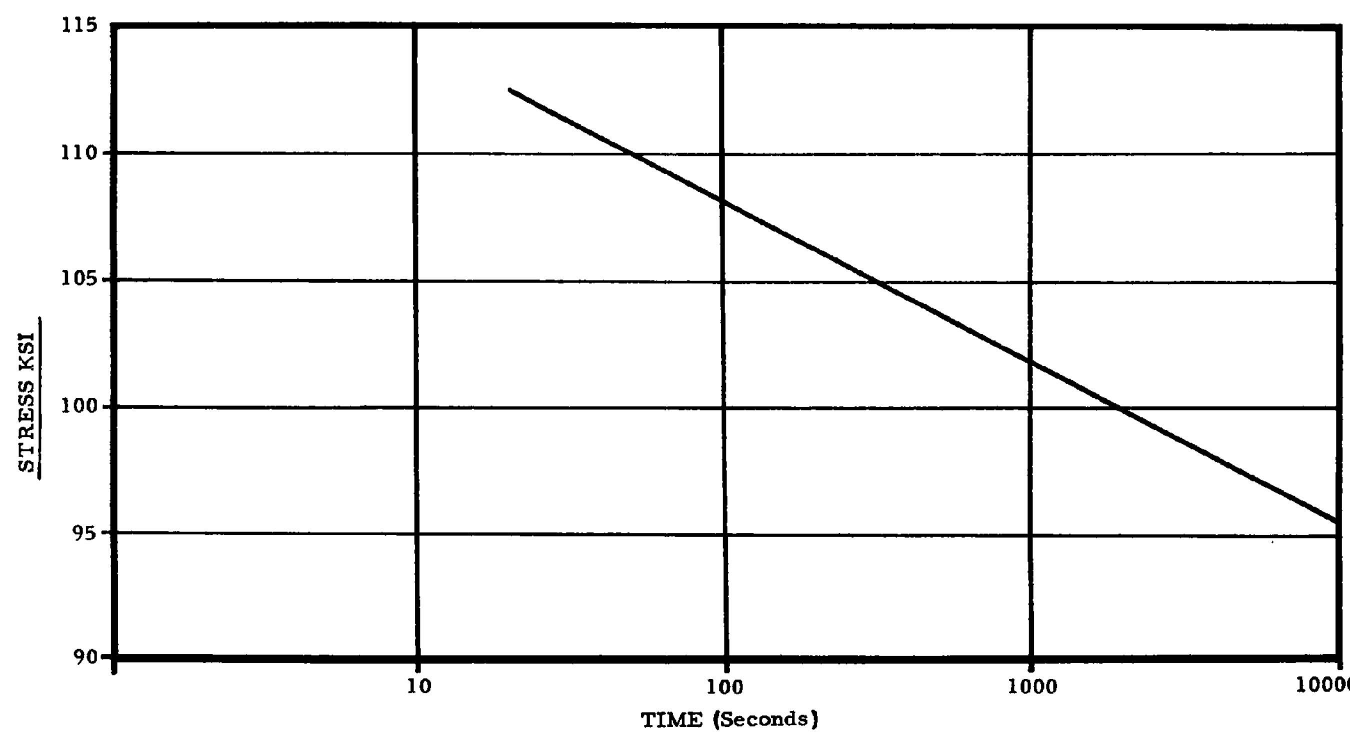


FIGURE 2. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 1500°F POWDER LOT "A"

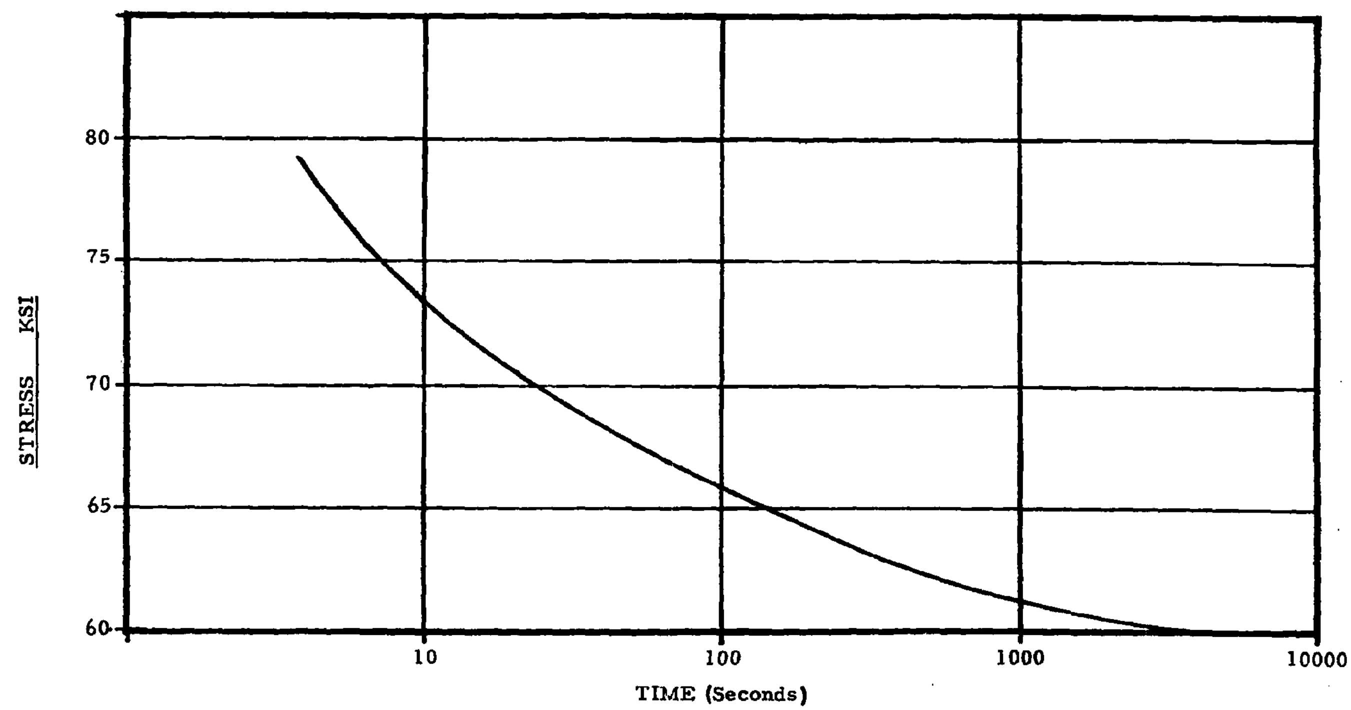


FIGURE 3. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 2000°F POWDER LOT "A"

FIGURE 4. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 2500°F POWDER LOT "A"

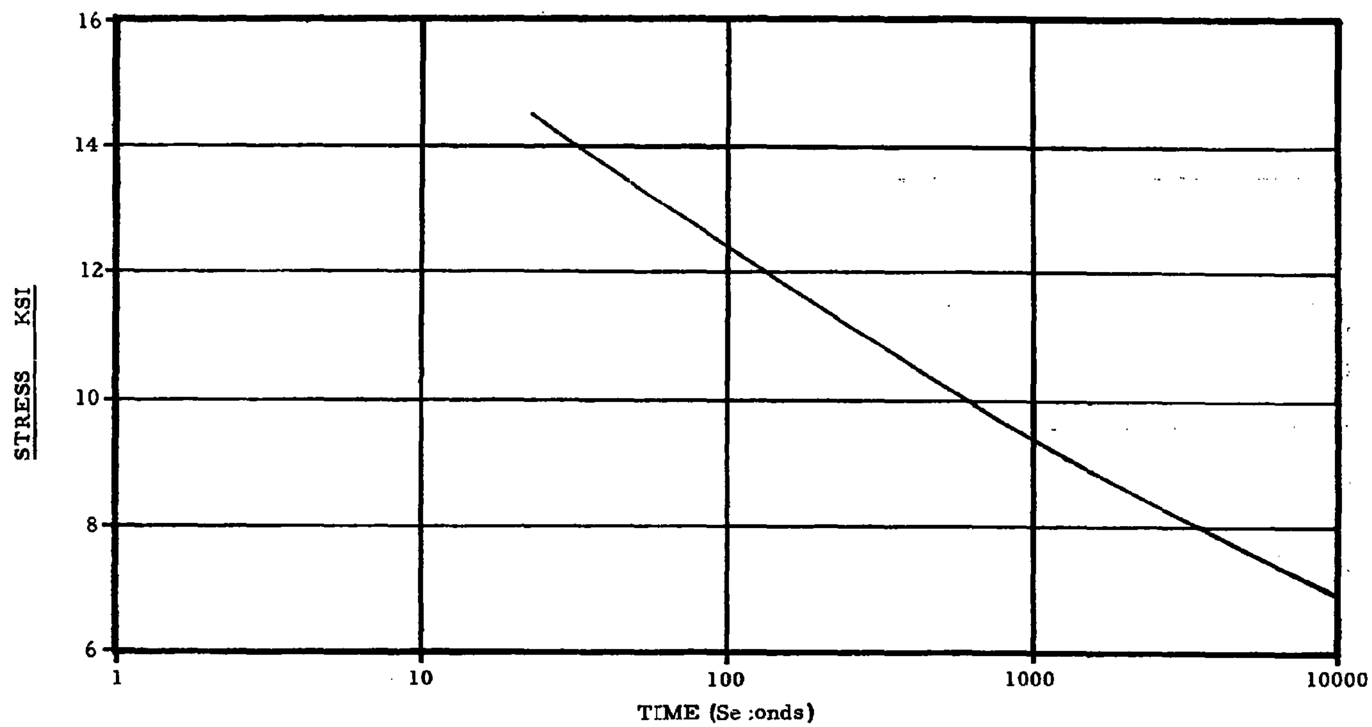


FIGURE 5. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 3000°F POWDER LOT "A"

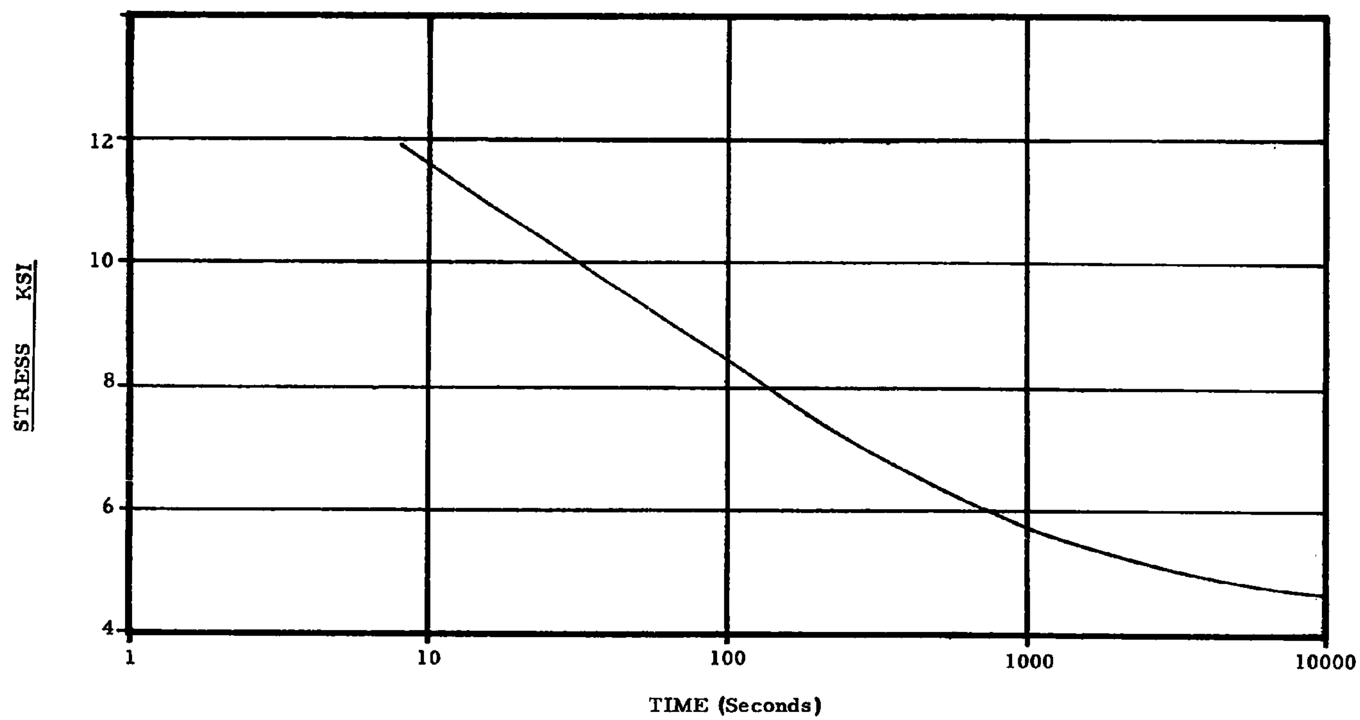


FIGURE 6. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 3500°F POWDER LOT "A"

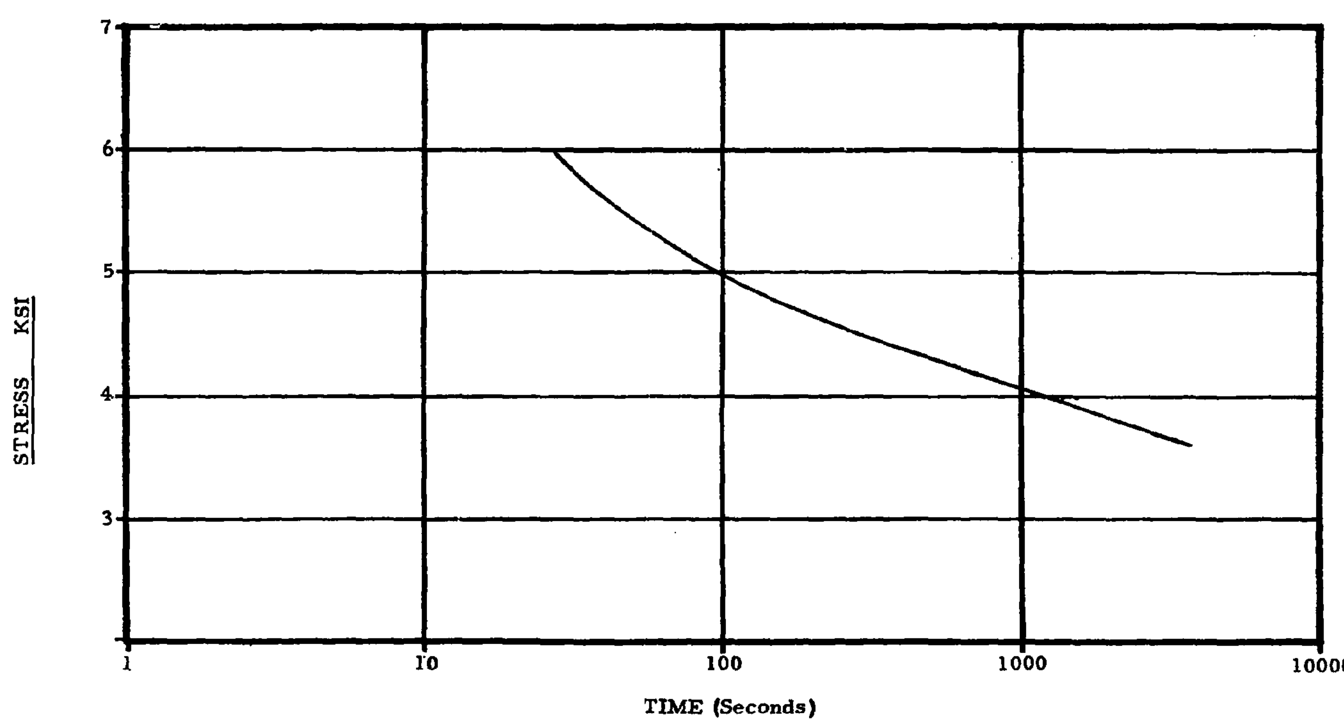


FIGURE 7. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 4000°F POWDER LOT "A"

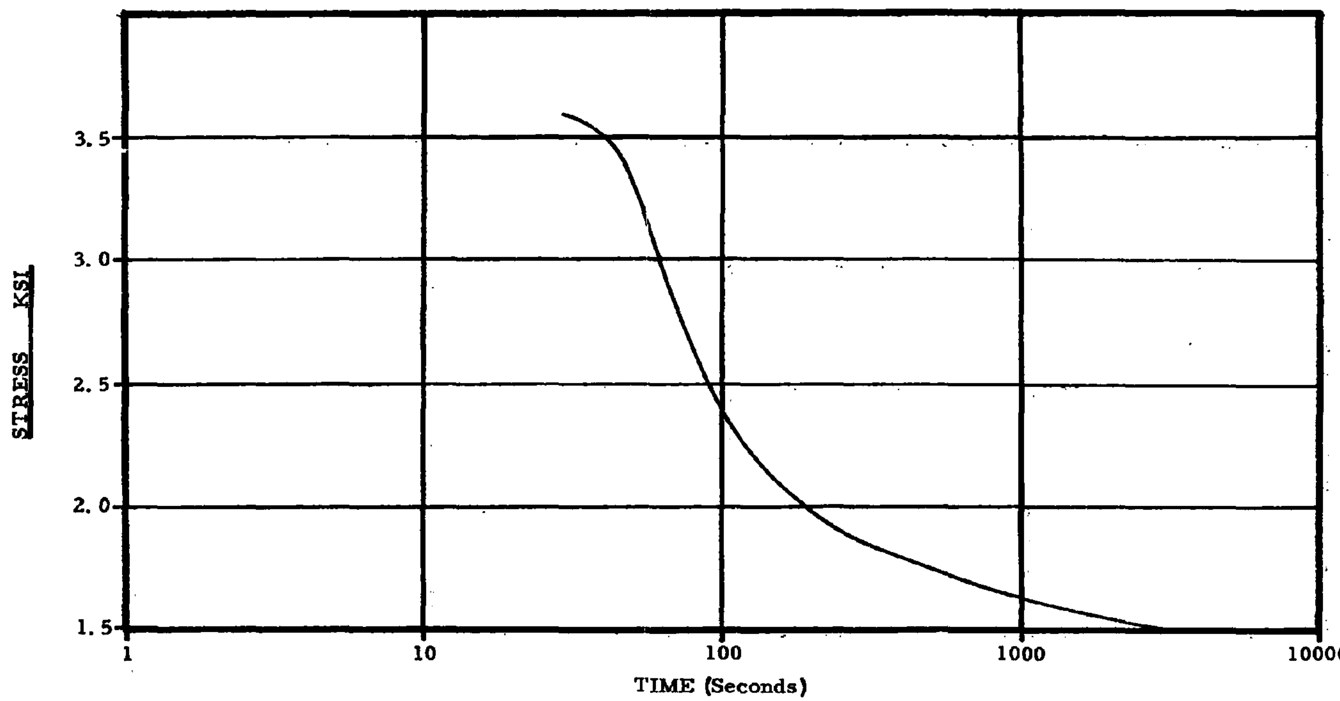


FIGURE 8. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 4500°F POWDER LOT "A"

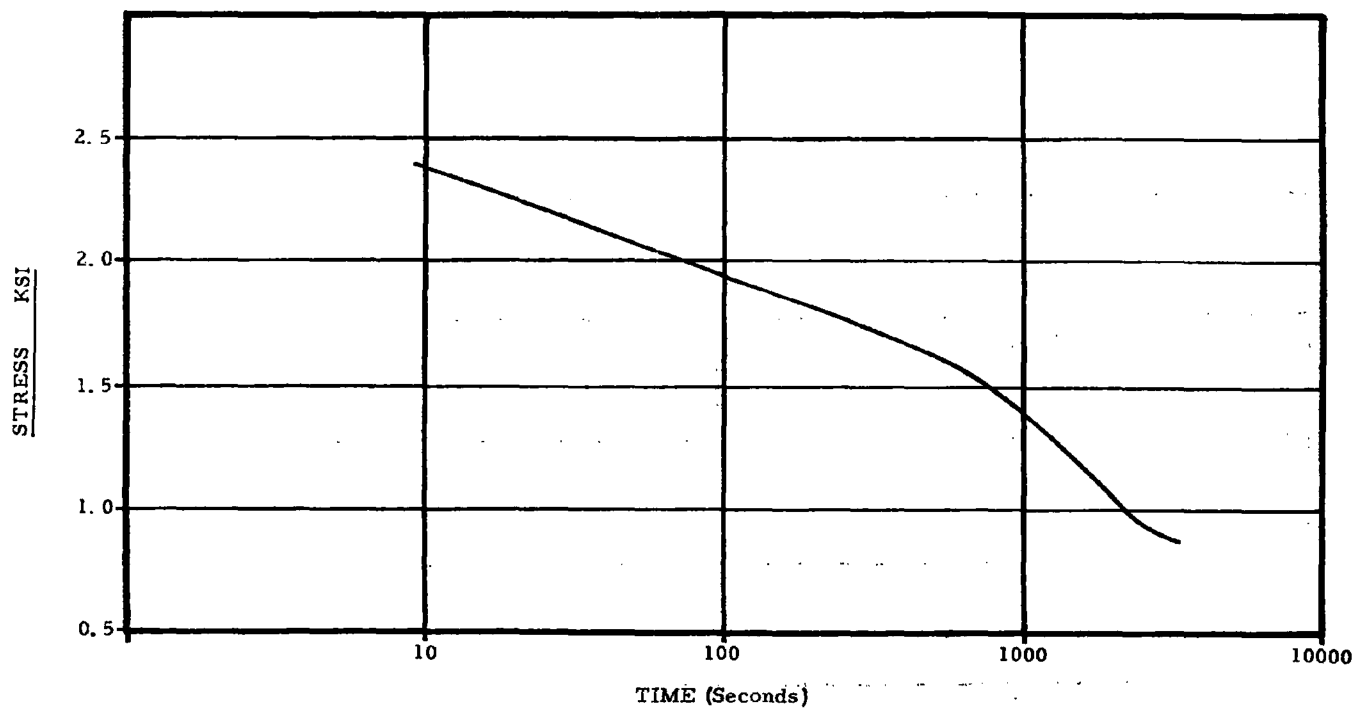


FIGURE 9. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 5000°F POWDER LOT "A"

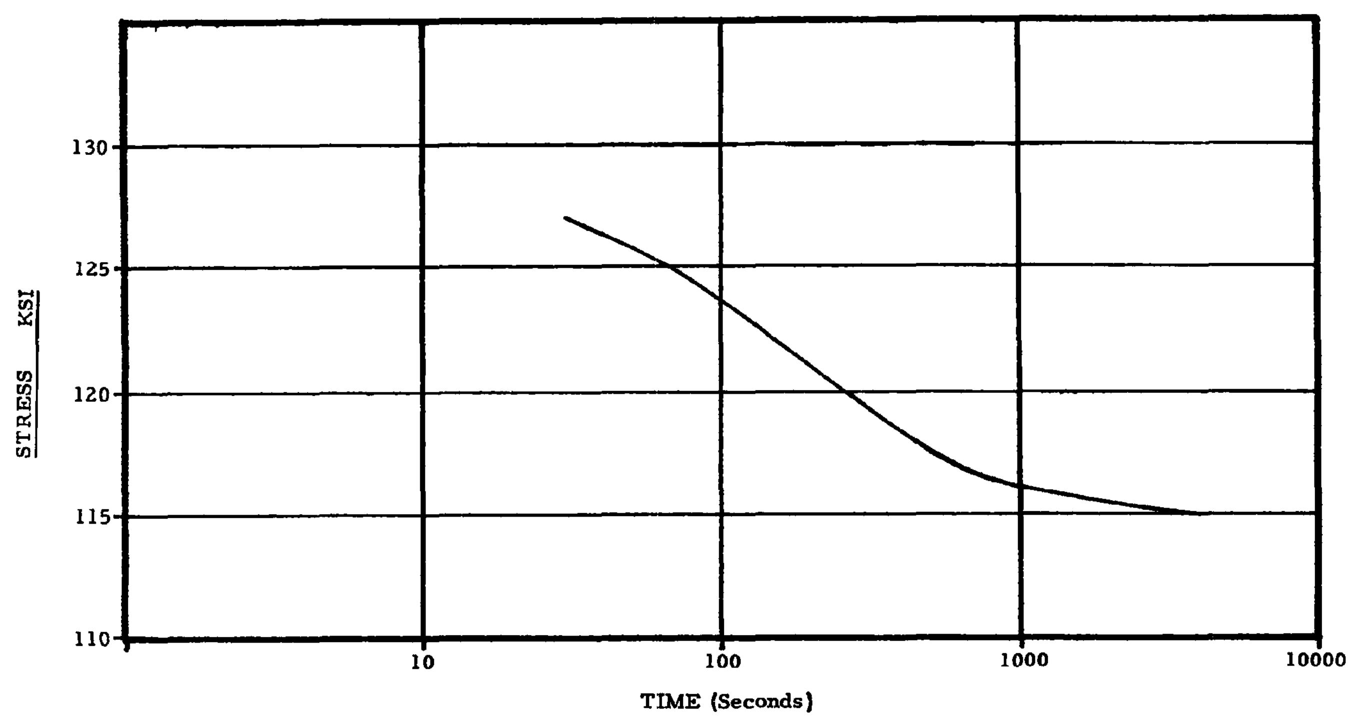


FIGURE 10. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 1500°F POWDER LOT "B"

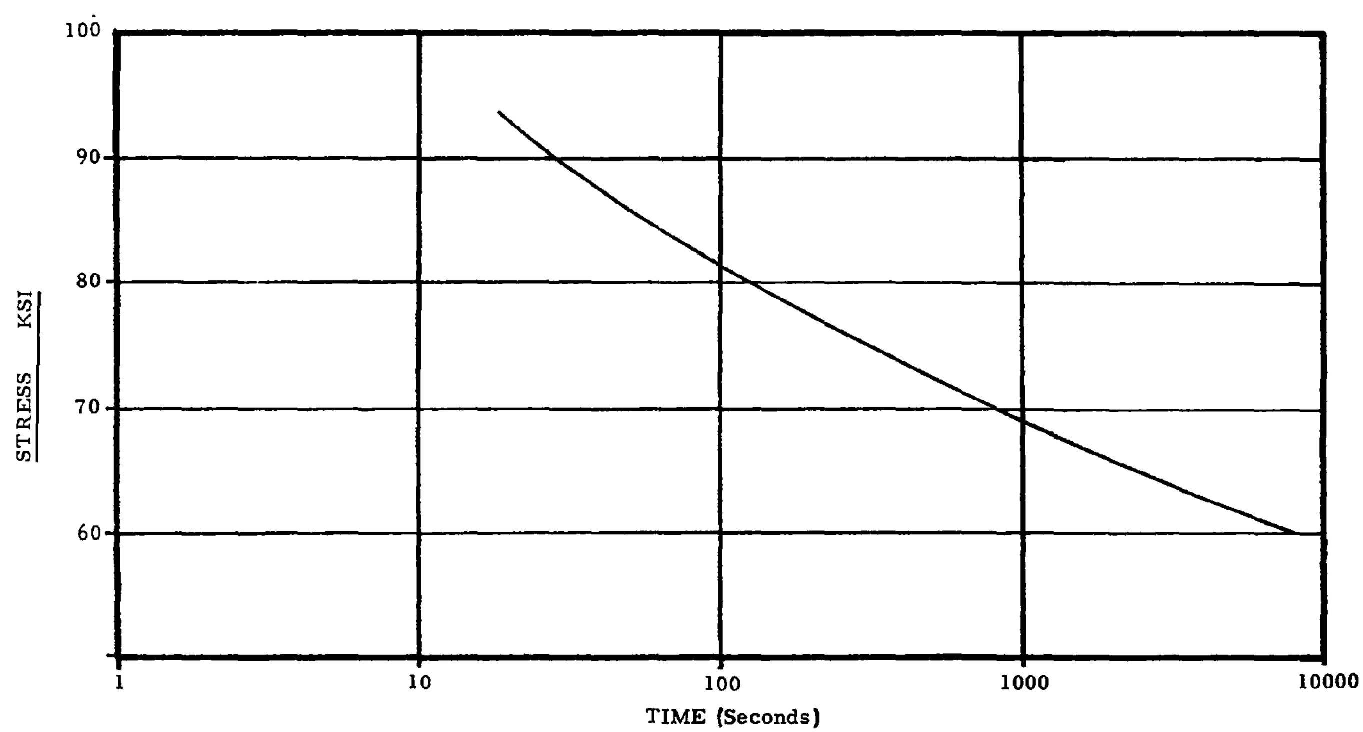


FIGURE 11. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 2000°F POWDER LOT "B"

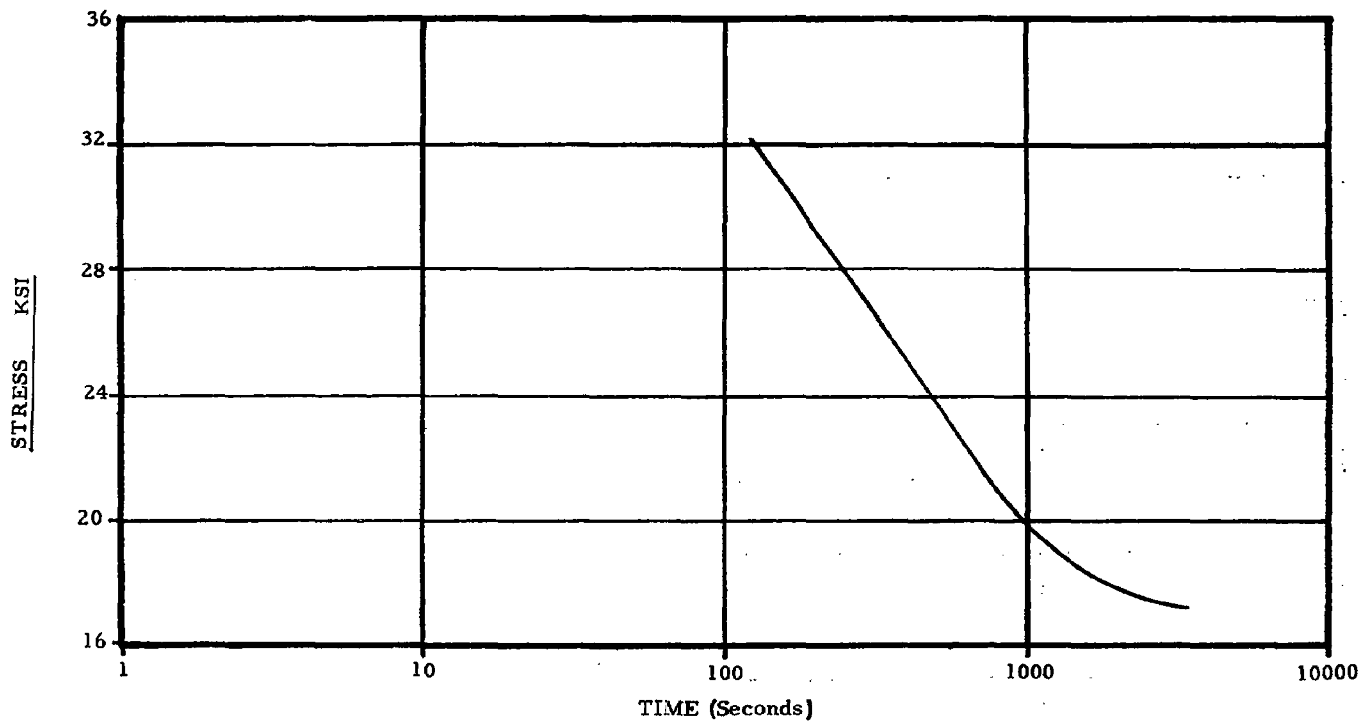


FIGURE 12. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 2500°F POWDER LOT "B"

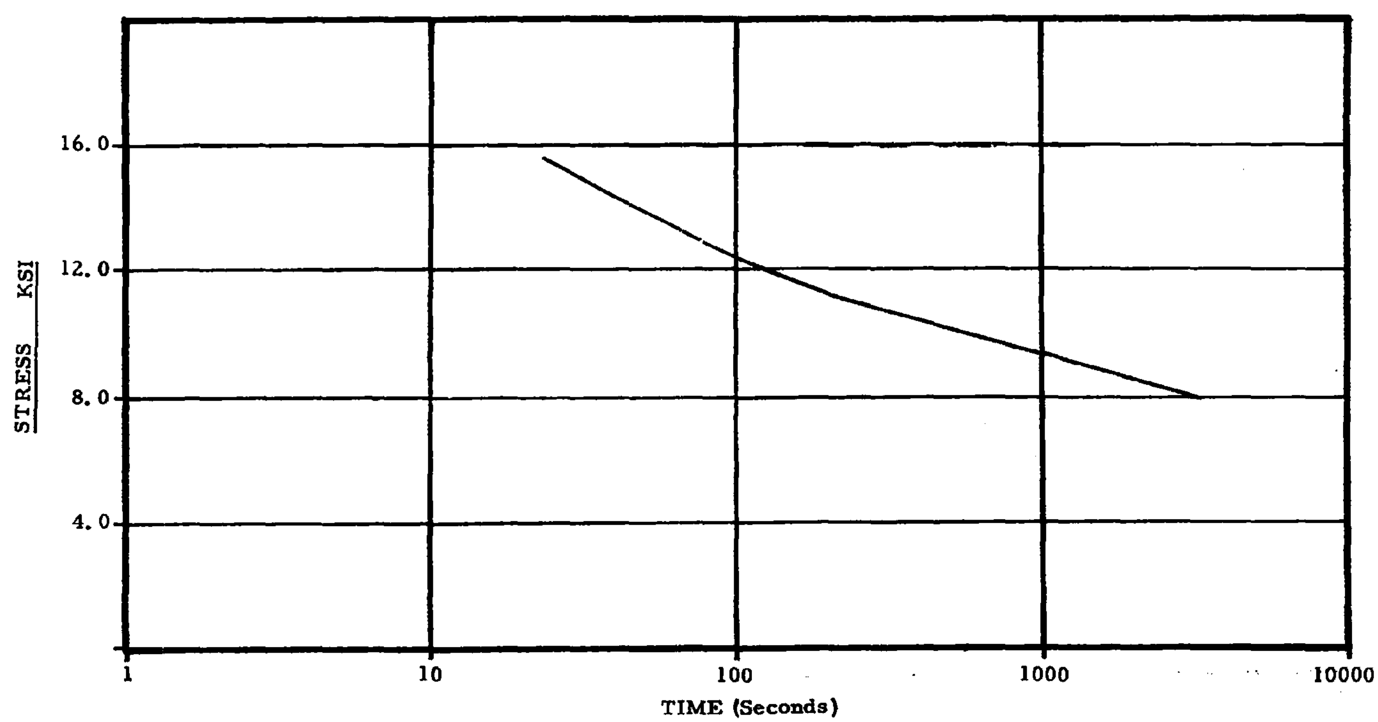


FIGURE 13. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 3000°F POWDER LOT "B"

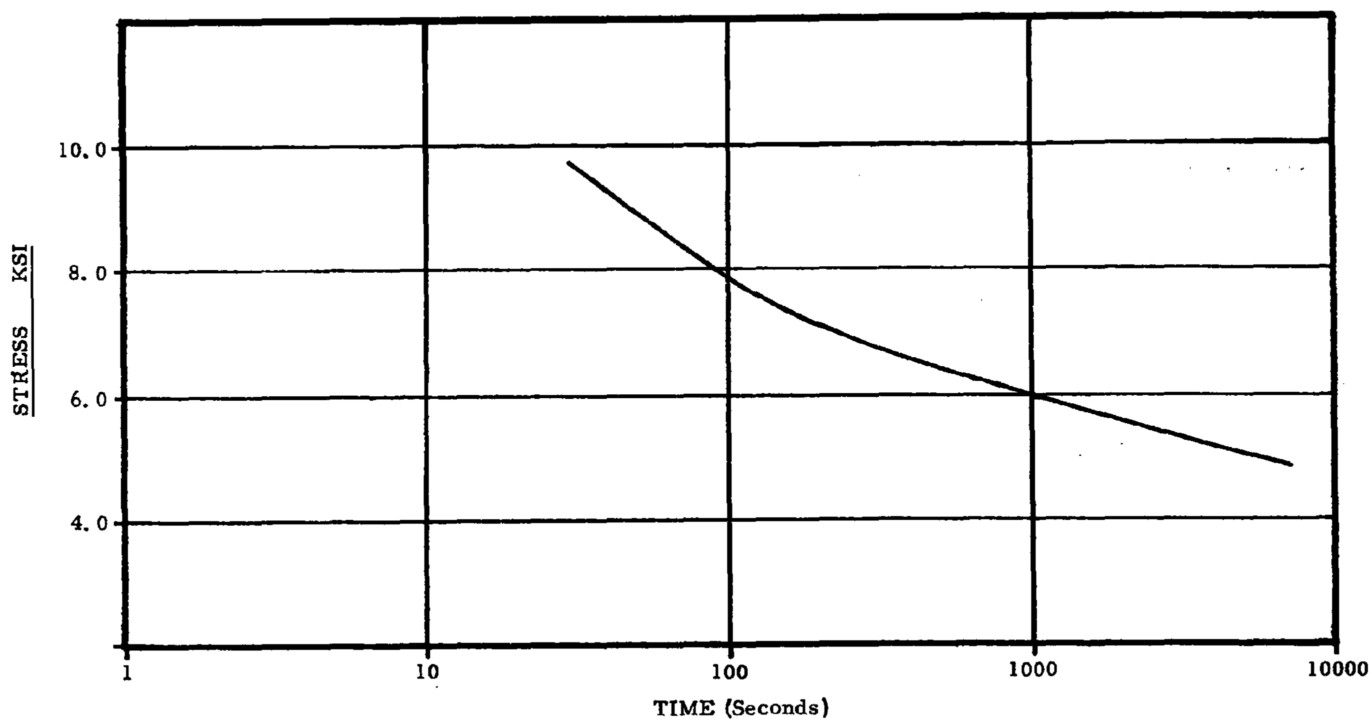


FIGURE 14. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 3500°F POWDER LOT "B"

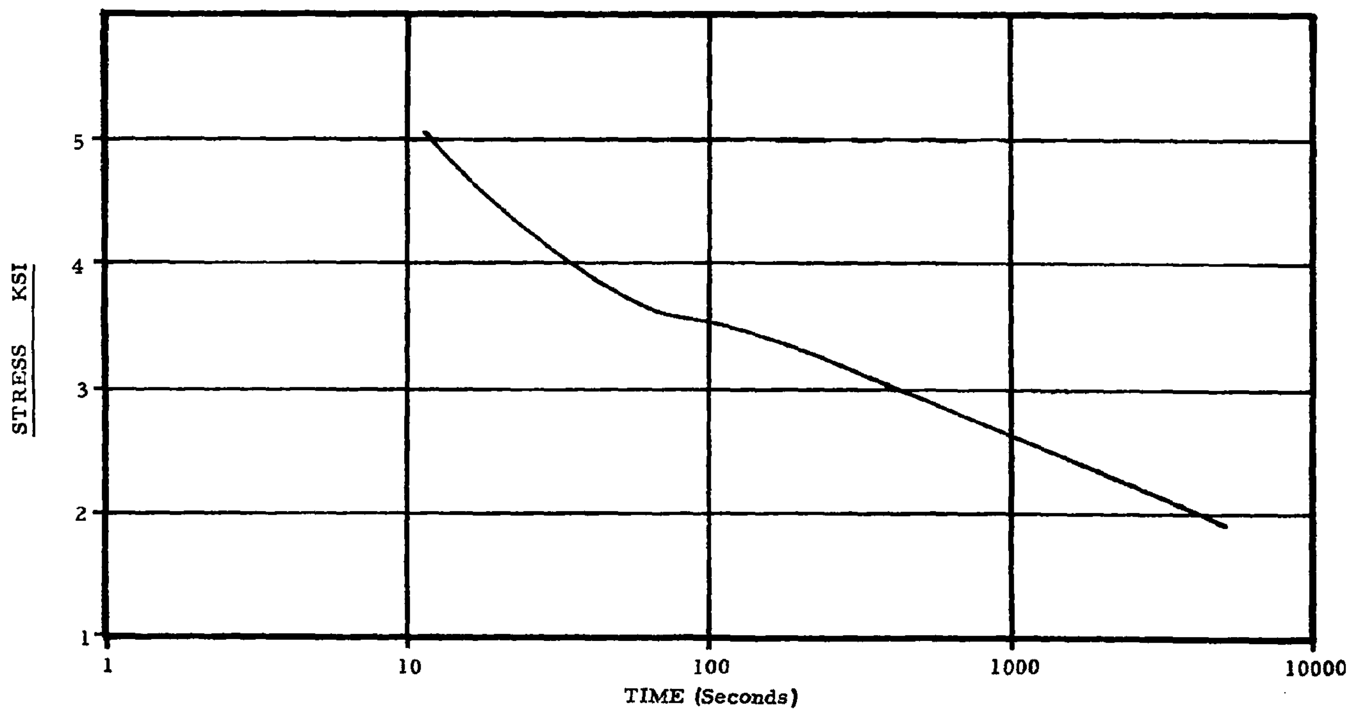


FIGURE 15. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 4000°F POWDER LOT "B"

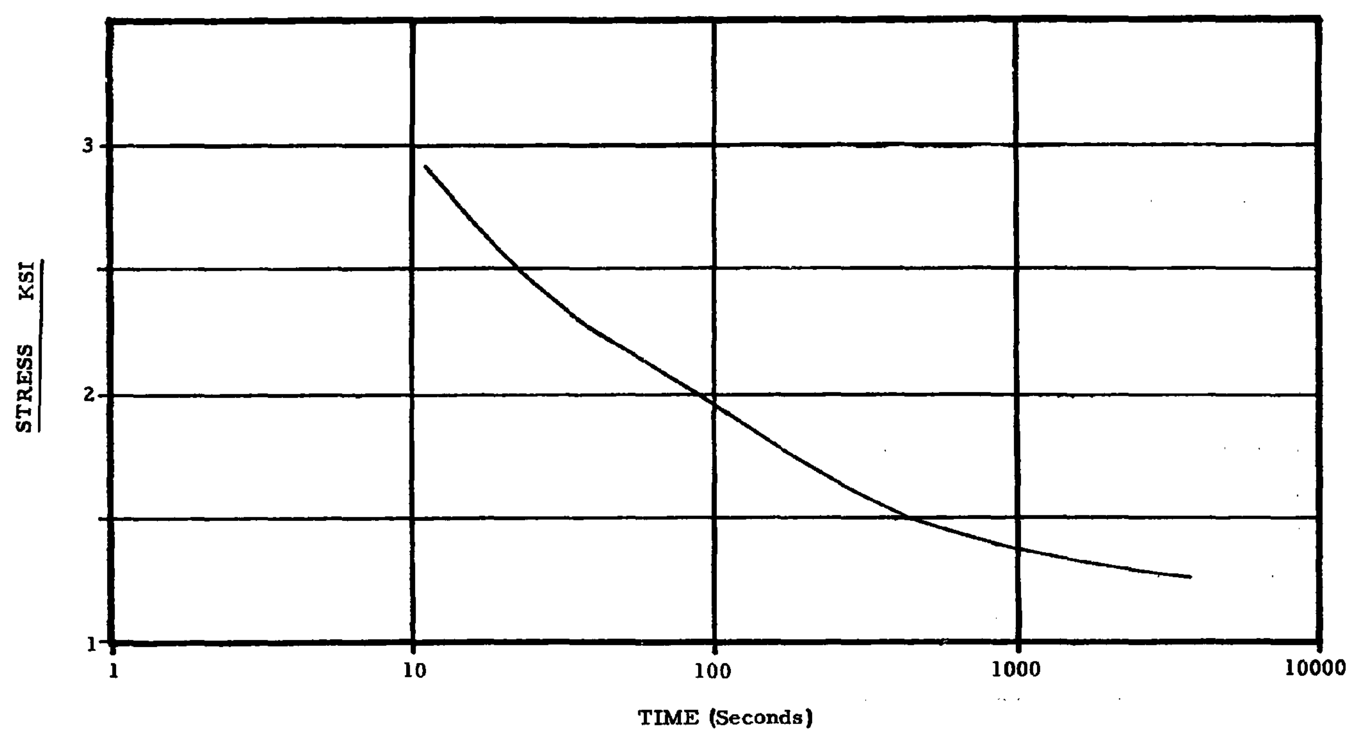


FIGURE 16. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 4500°F POWDER LOT "B"

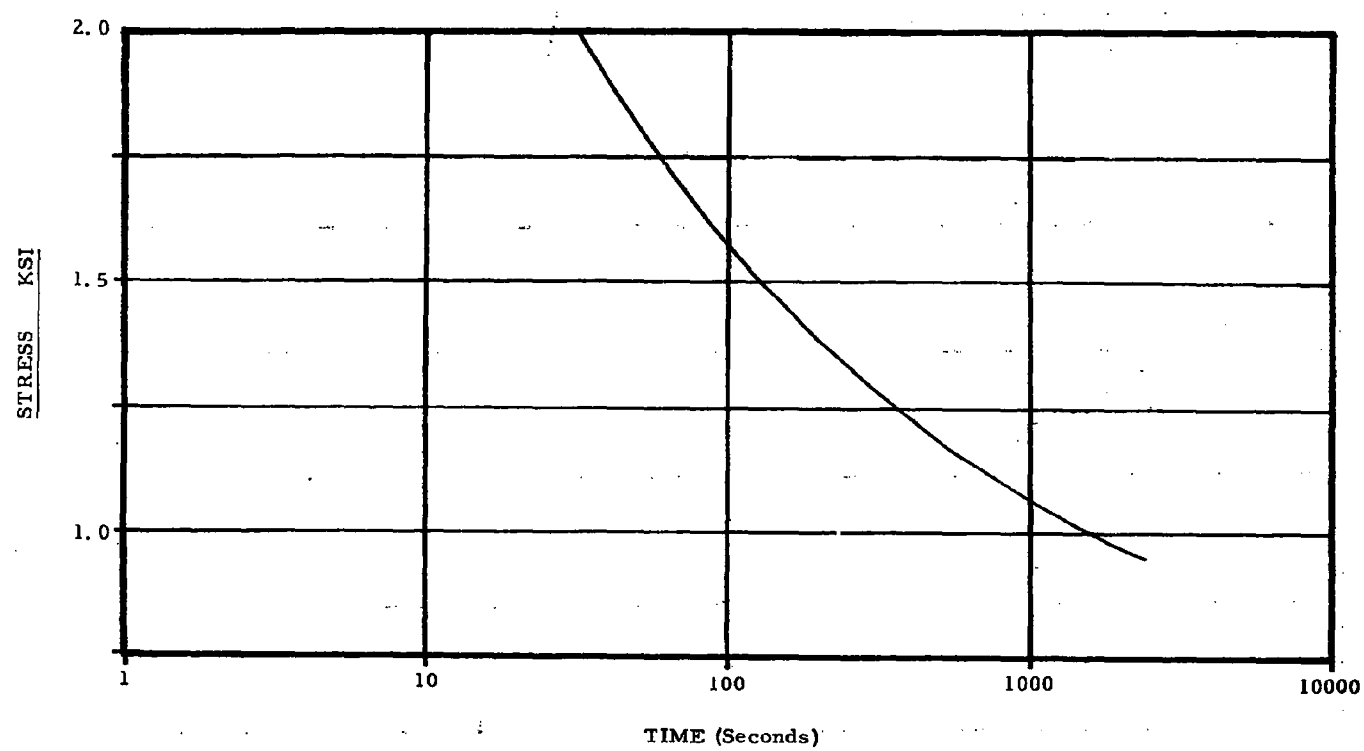


FIGURE 17. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 5000°F POWDER LOT "B".

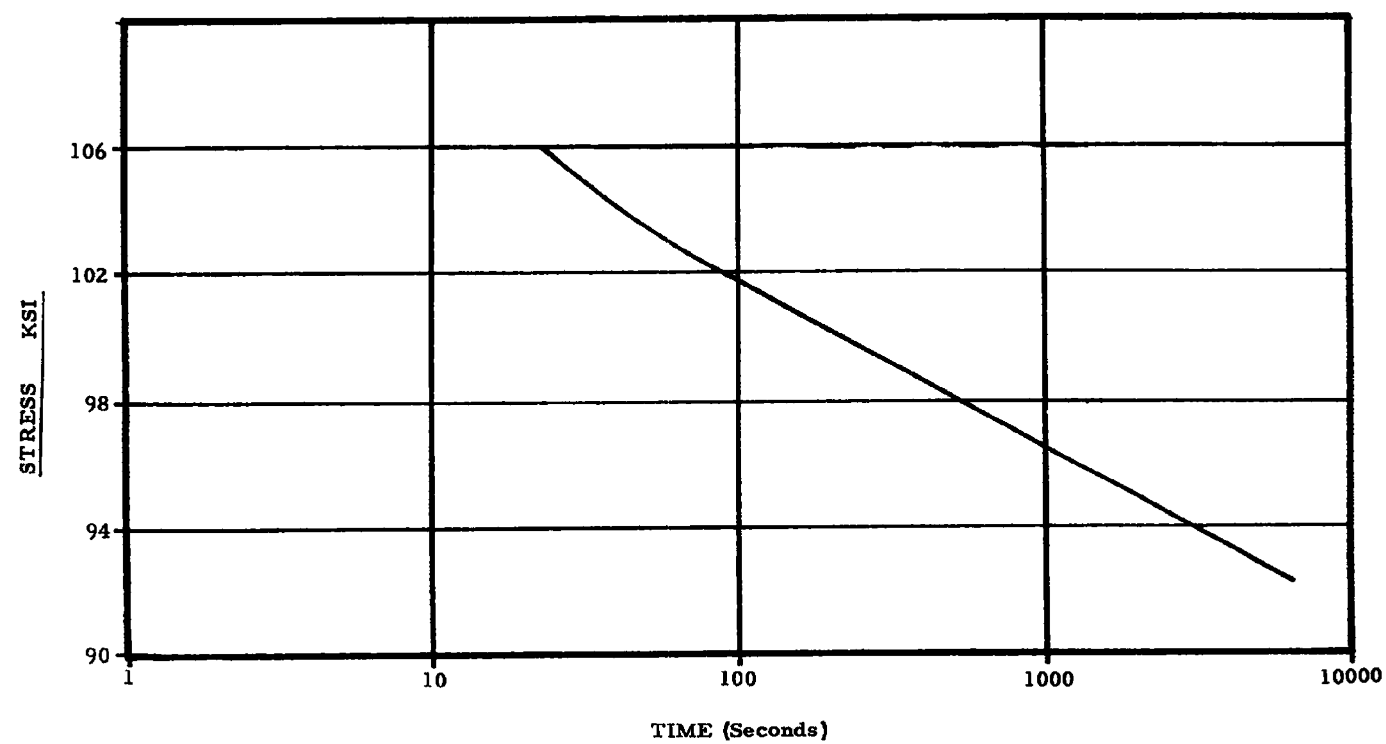


FIGURE 18. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 1500°F POWDER LOT "C"

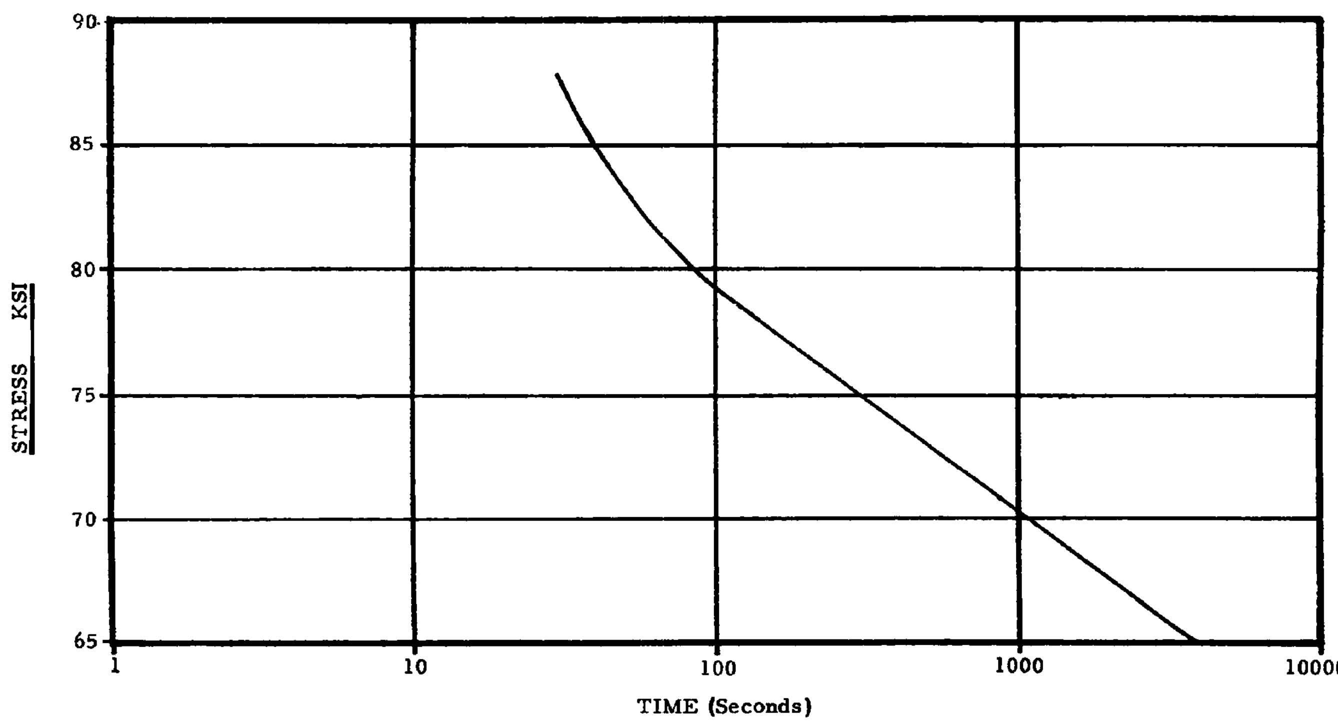


FIGURE 19. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 2000°F POWDER LOT "C"

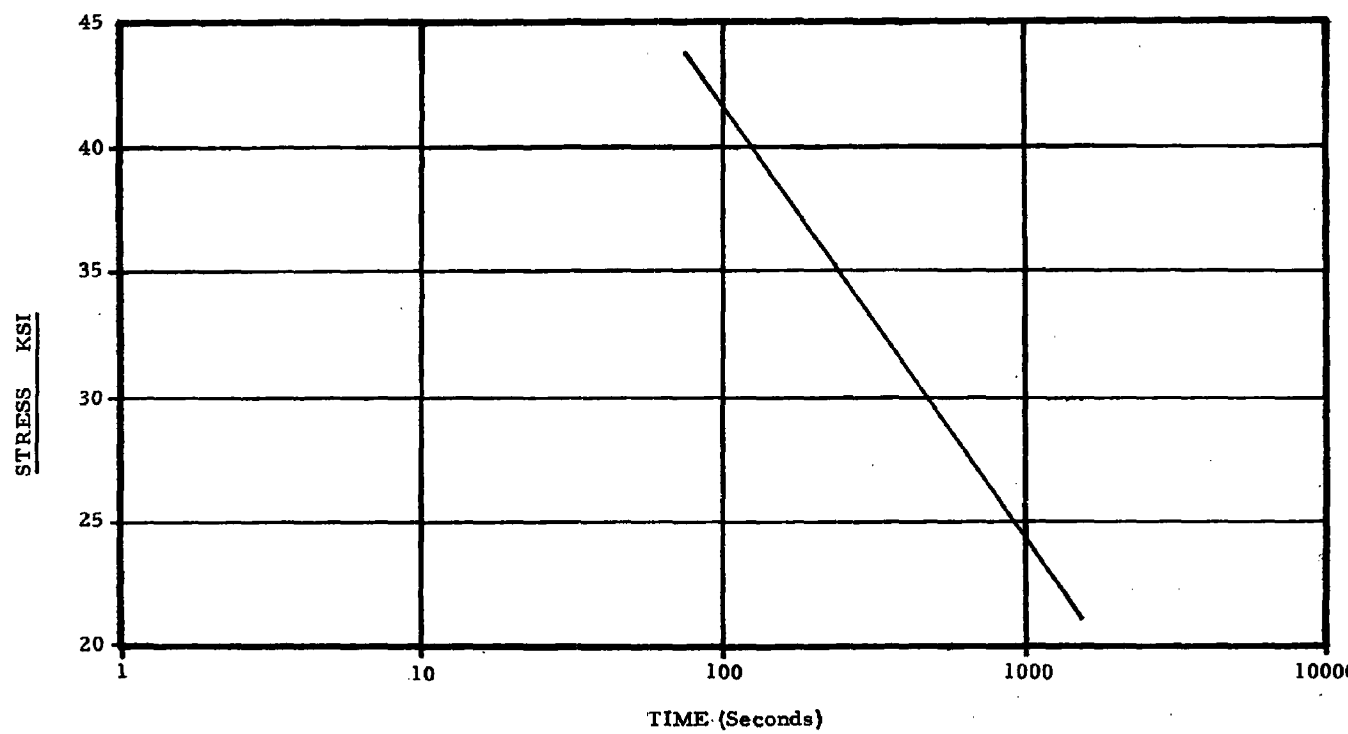


FIGURE 20. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 2500°F POWDER LOT "C"

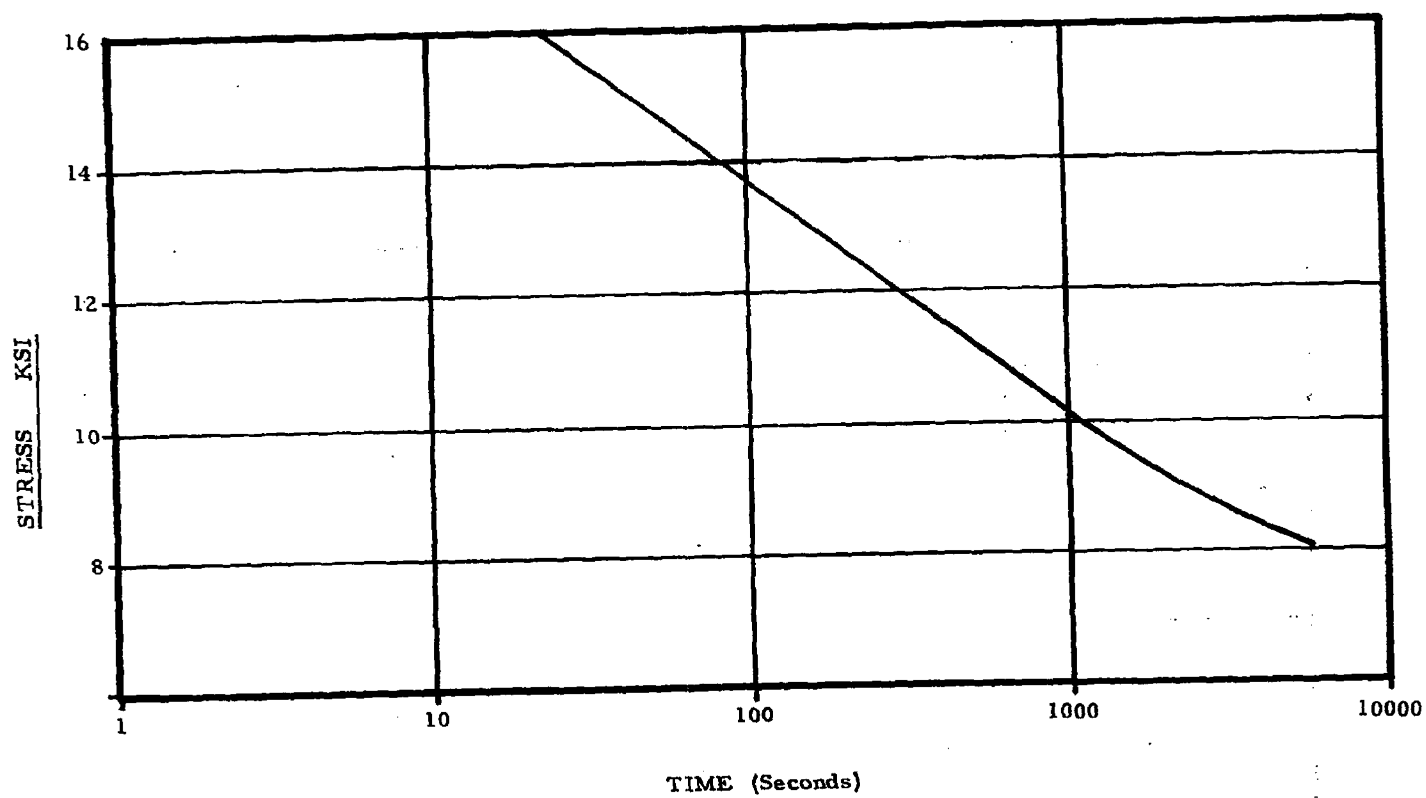


FIGURE 21. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 3000°F POWDER LOT "C"

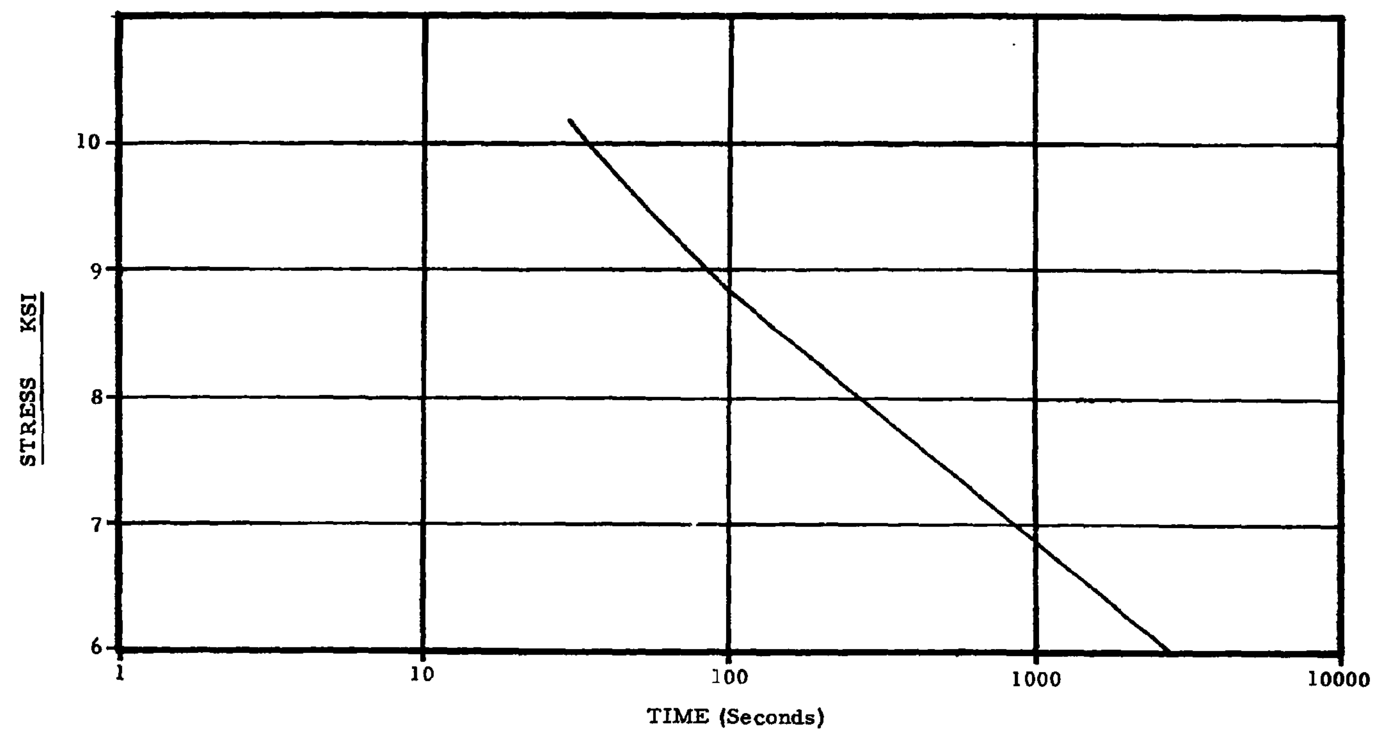


FIGURE 22. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 3500°F POWDER LOT "C"

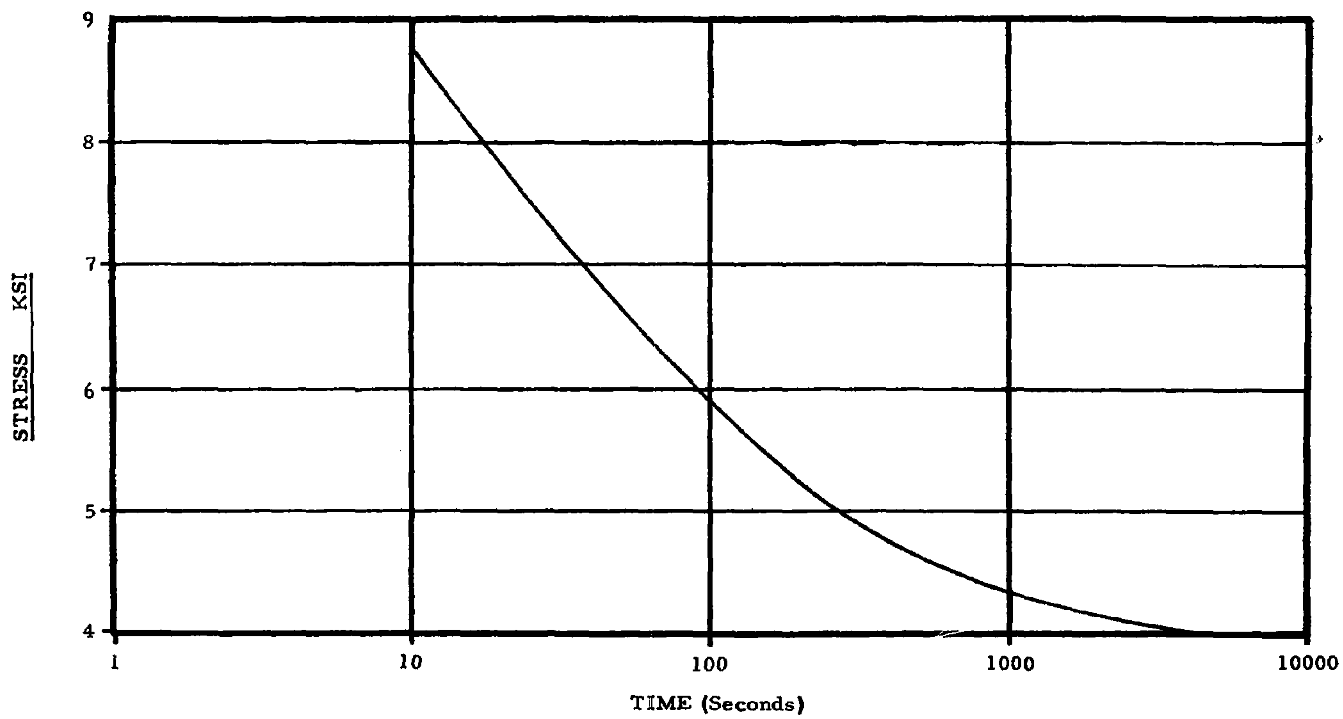


FIGURE 23. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 4000°F POWDER LOT "C"

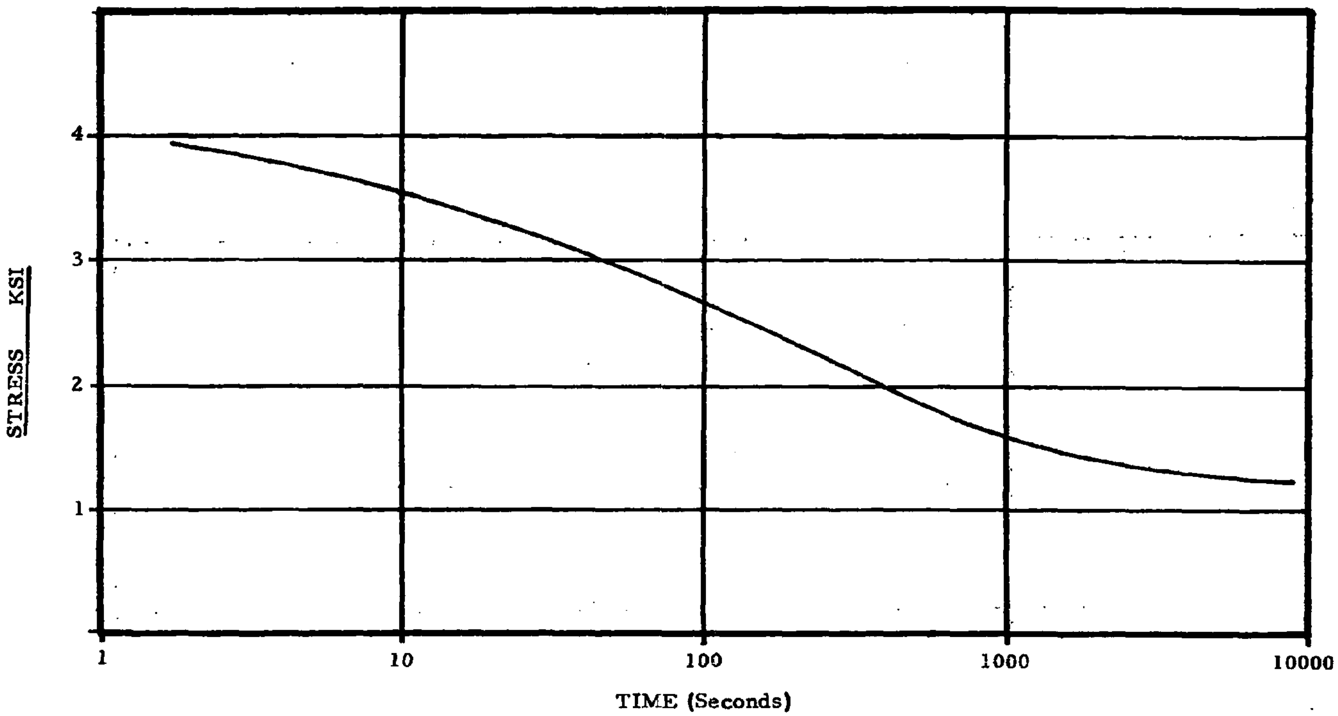


FIGURE 24. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 4500°F POWDER LOT "C"

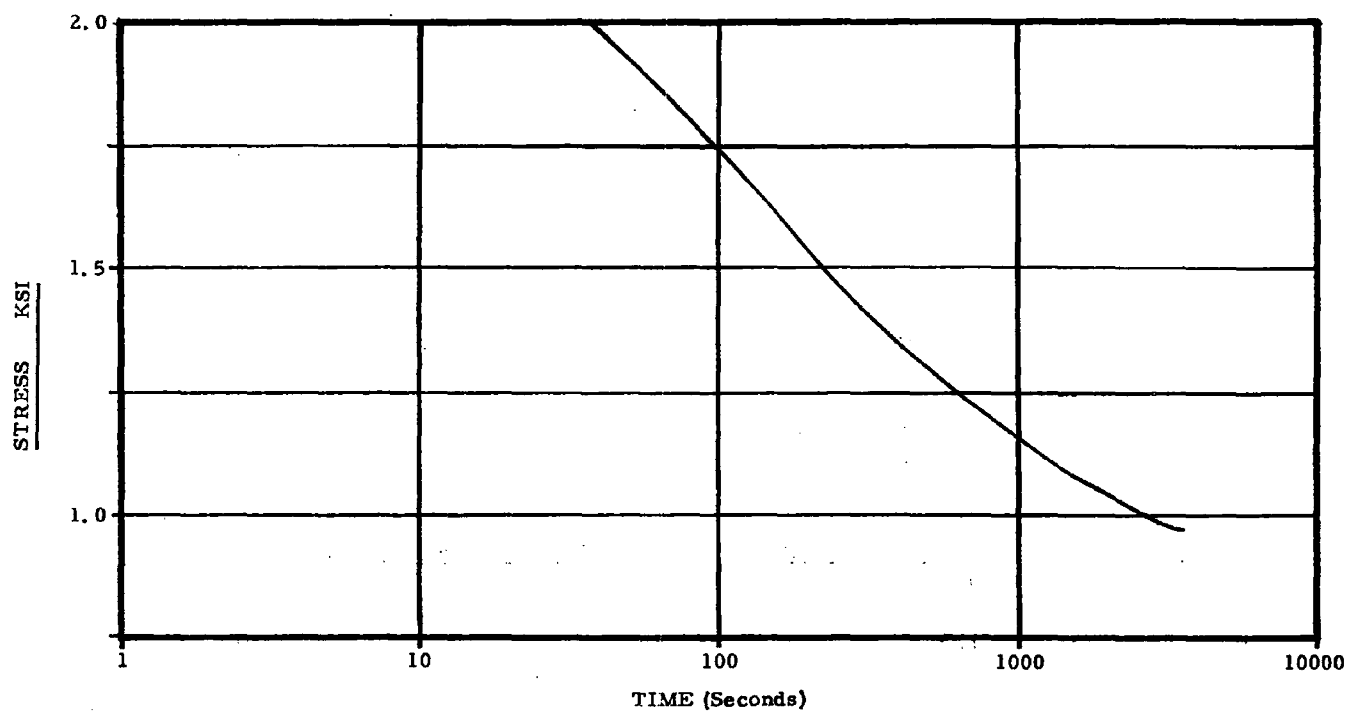


FIGURE 25. 2% CREEP RUPTURE PROPERTIES (MINIMUMS) OF COMMERCIALLY PURE (FANSTEEL) .050" THICK TUNGSTEN SHEET AT 5000°F POWDER LOT "C"

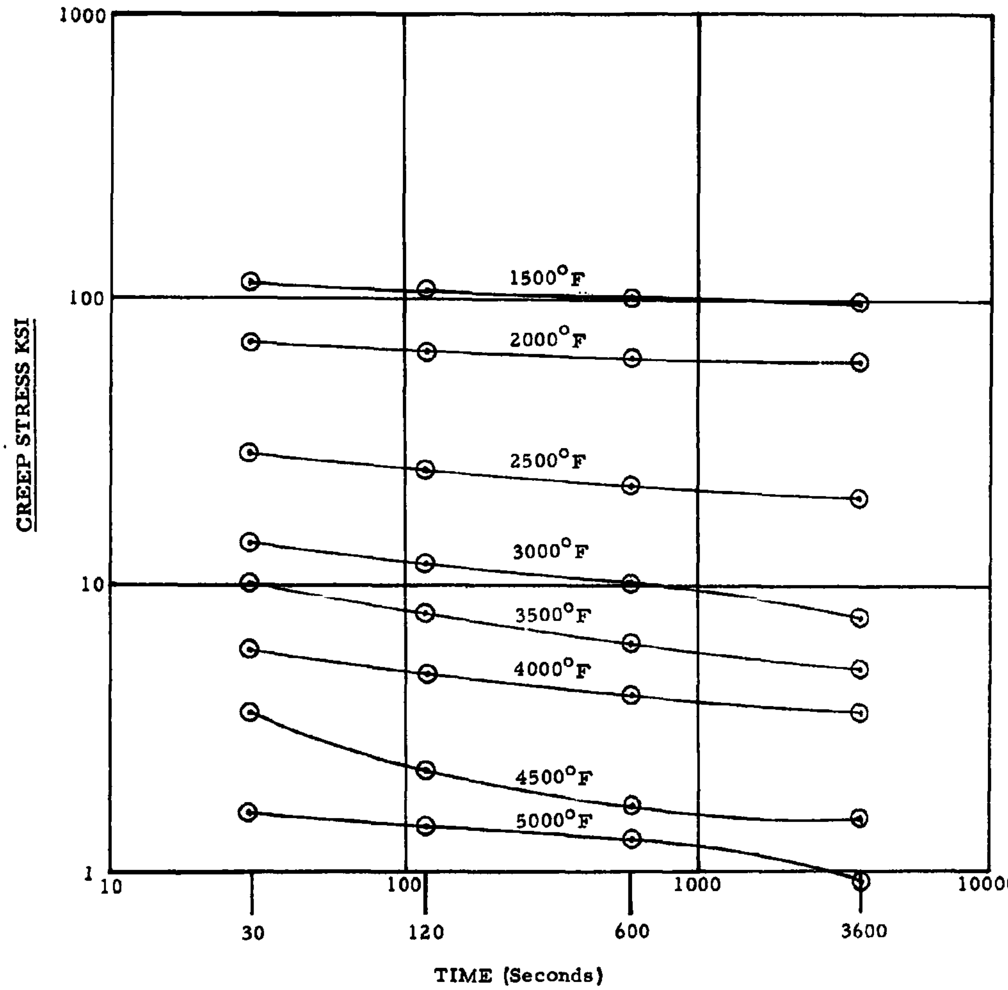


FIGURE 26. TIME AND STRESS REQUIRED TO REACH 2% CREEP AT VARIOUS TEST TEMPERATURES

POWDER LOT A

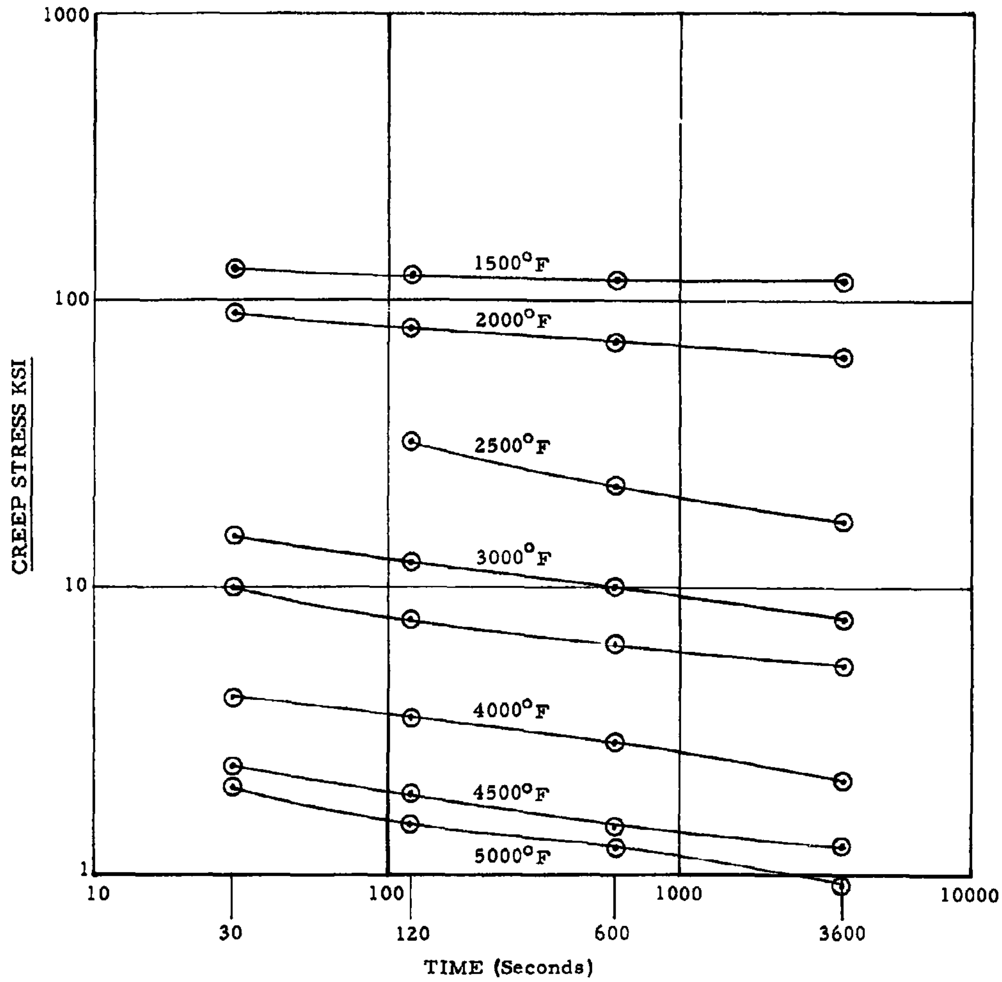


FIGURE 27. TIME AND STRESS REQUIRED TO REACH 2% CREEP AT VARIOUS TEST TEMPERATURES

POWDER LOT B

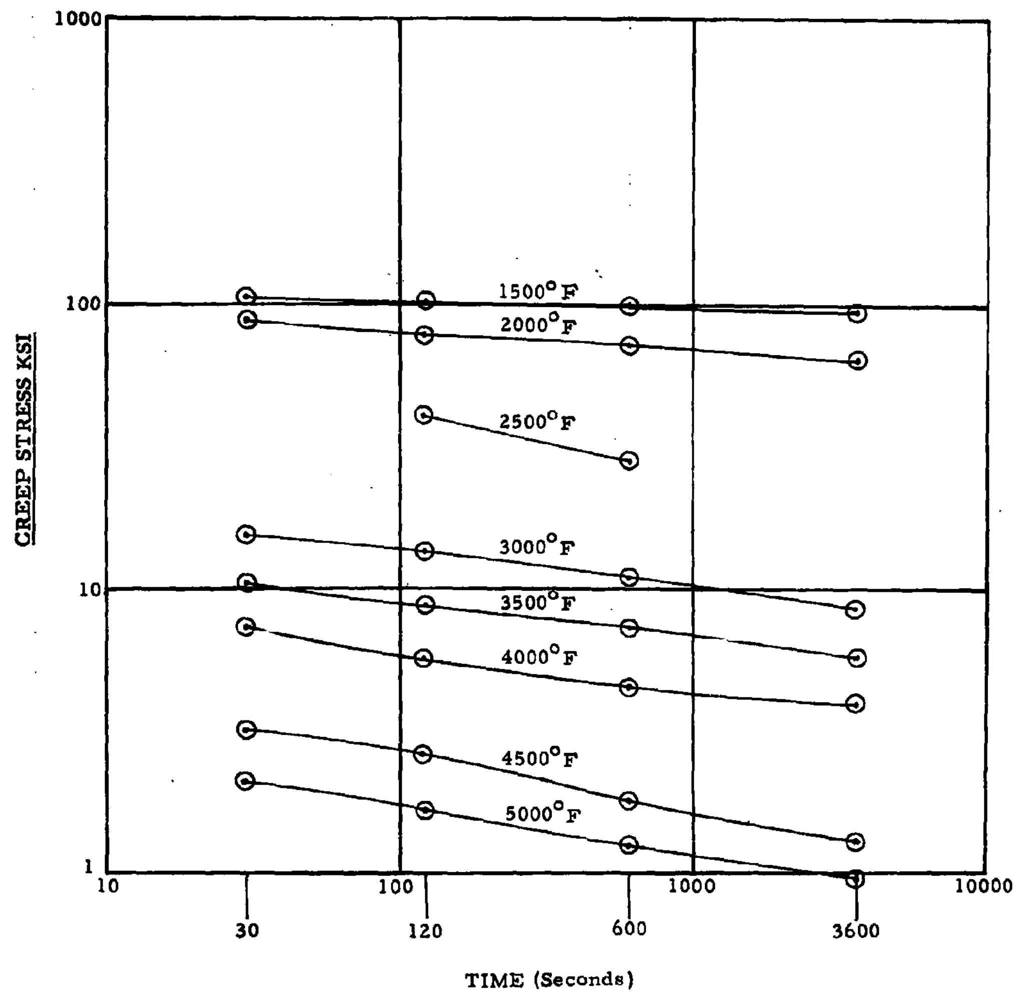


FIGURE 28. TIME AND STRESS REQUIRED TO REACH 2% CREEP AT VARIOUS TEST TEMPERATURES

POWDER LOT C

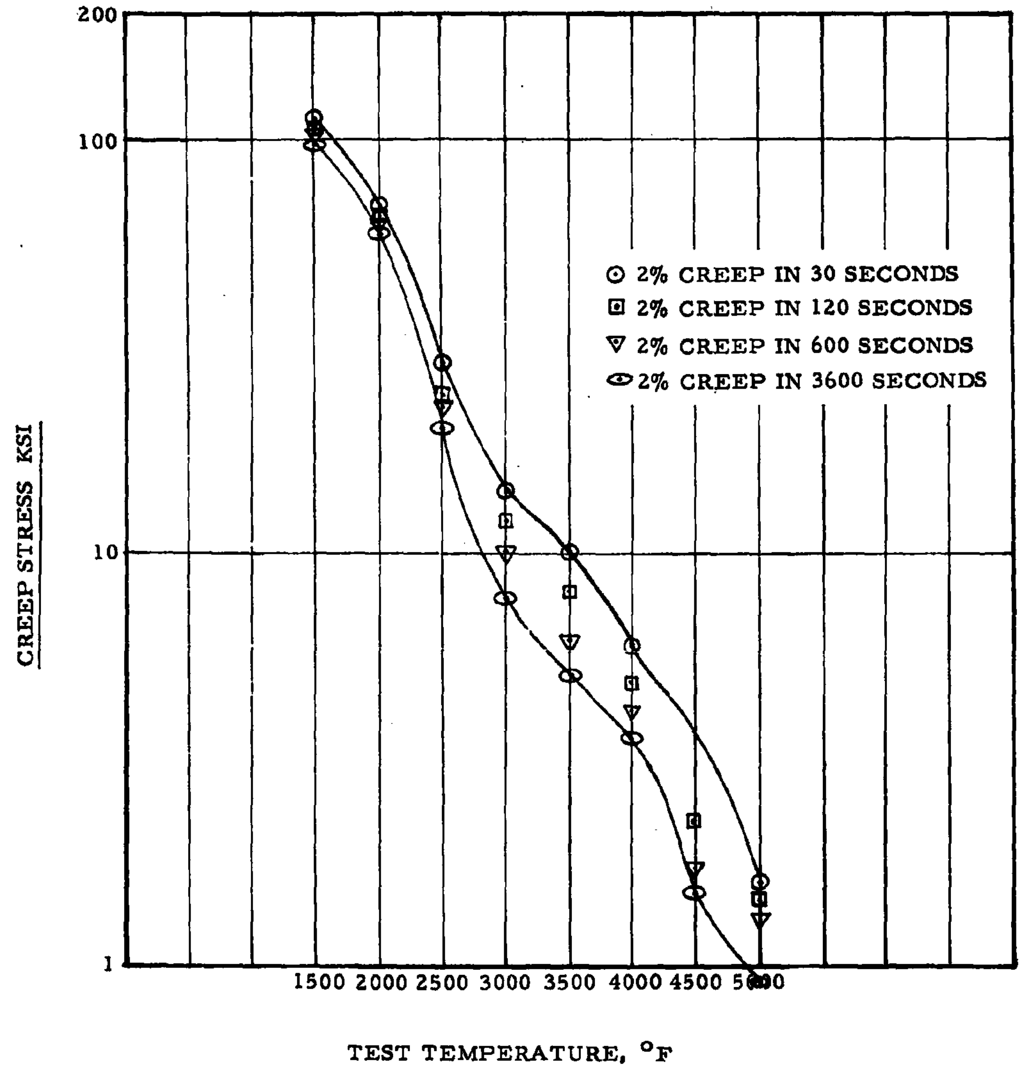


FIGURE 29. MINIMUM STRESS REQUIRED TO REACH 2% CREEP AT TEMPERATURES FROM 1500°F to 5000°F

POWDER LOT A

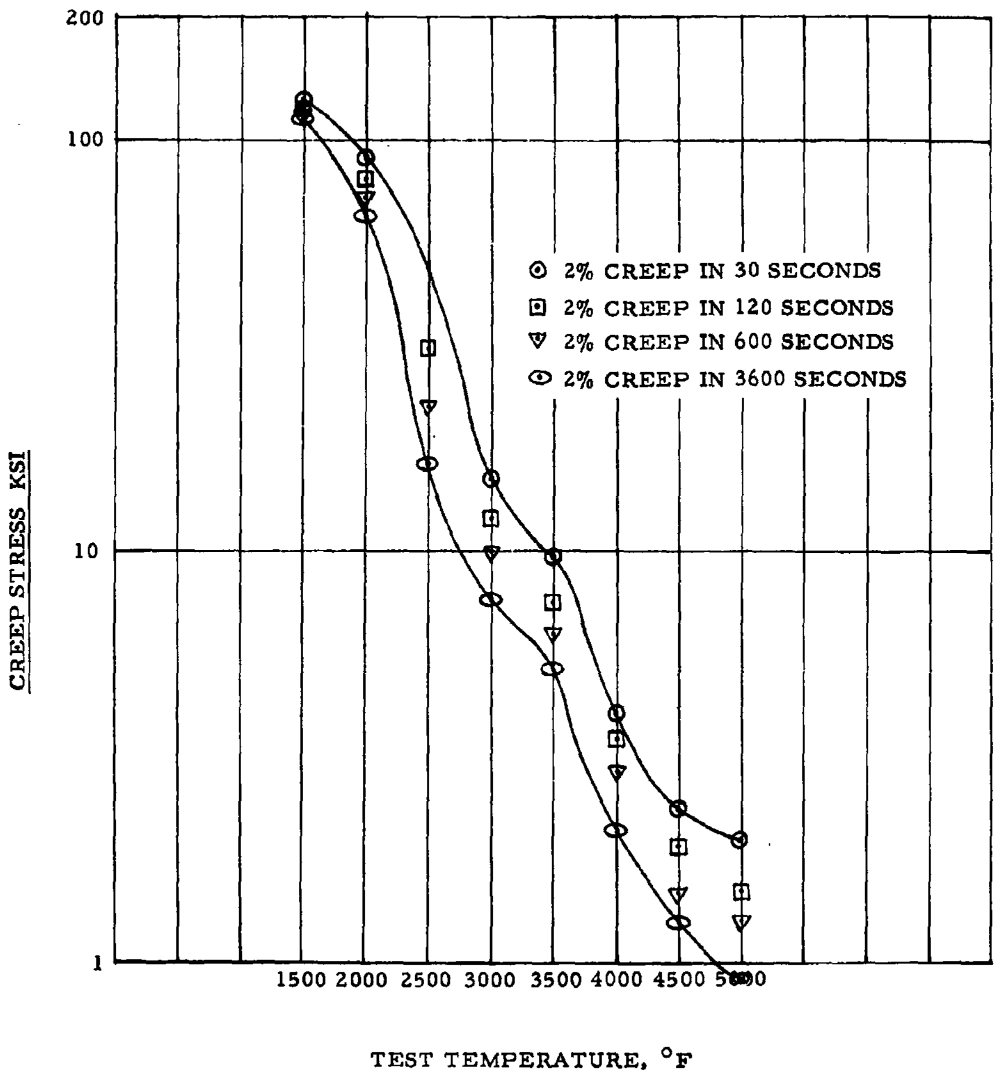


FIGURE 30. MINIMUM STRESS REQUIRED TO REACH 2% CREEP AT TEMPERATURES FROM 1500°F TO 5000°F

POWDER LOT B

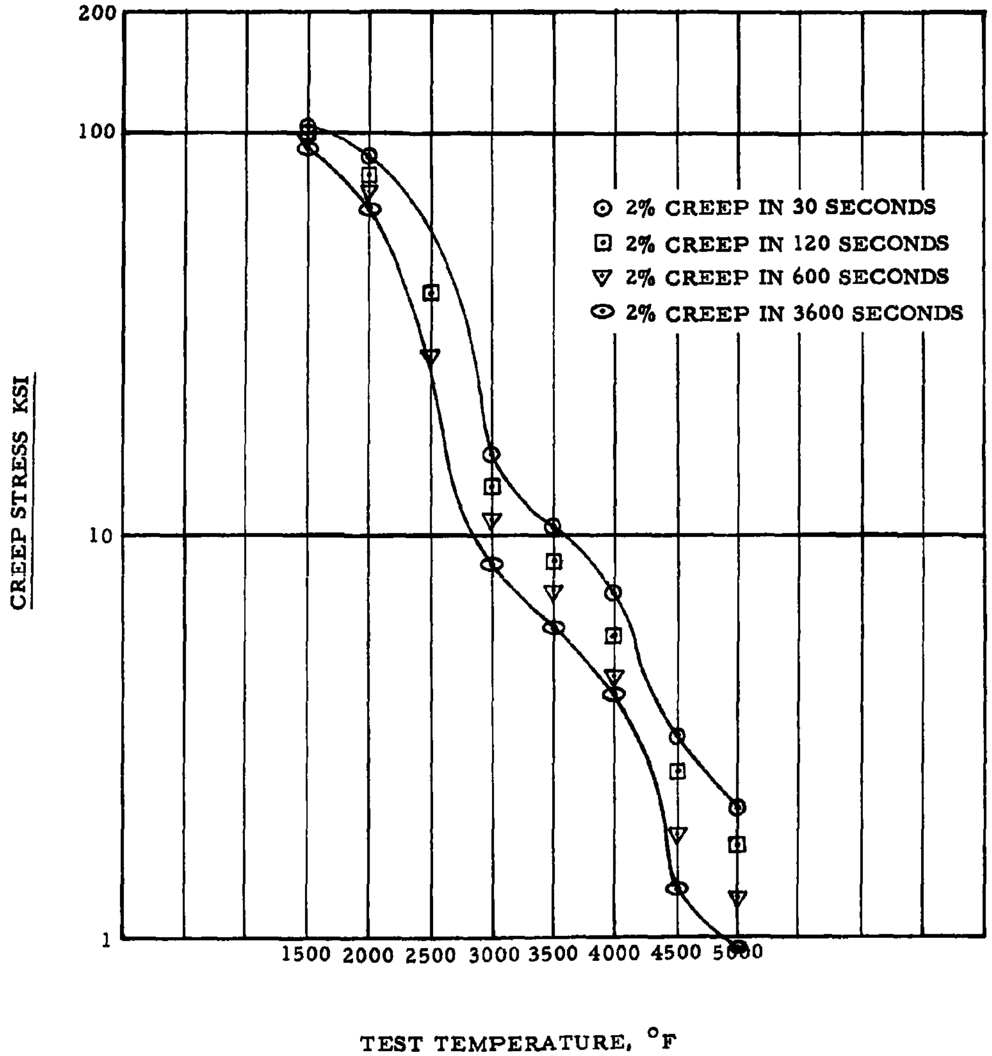


FIGURE 31. MINIMUM STRESS REQUIRED TO REACH 2% CREEP AT TEMPERATURES FROM 1500°F TO 5000°F

POWDER LOT C

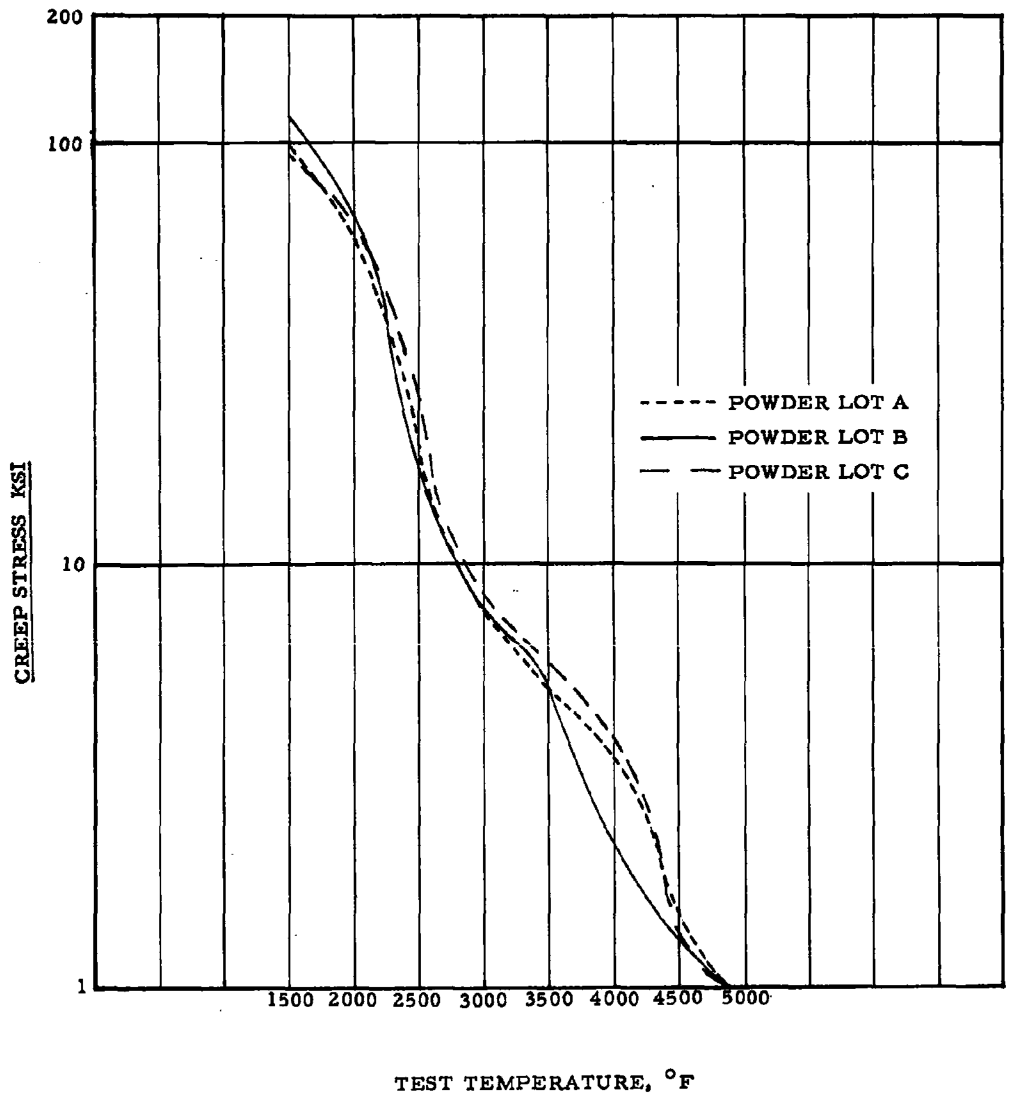


FIGURE 32. MINIMUM STRESS REQUIRED TO REACH 2% CREEP IN 30 SECONDS AT TEMPERATURES FROM 1500°F TO 5000°F

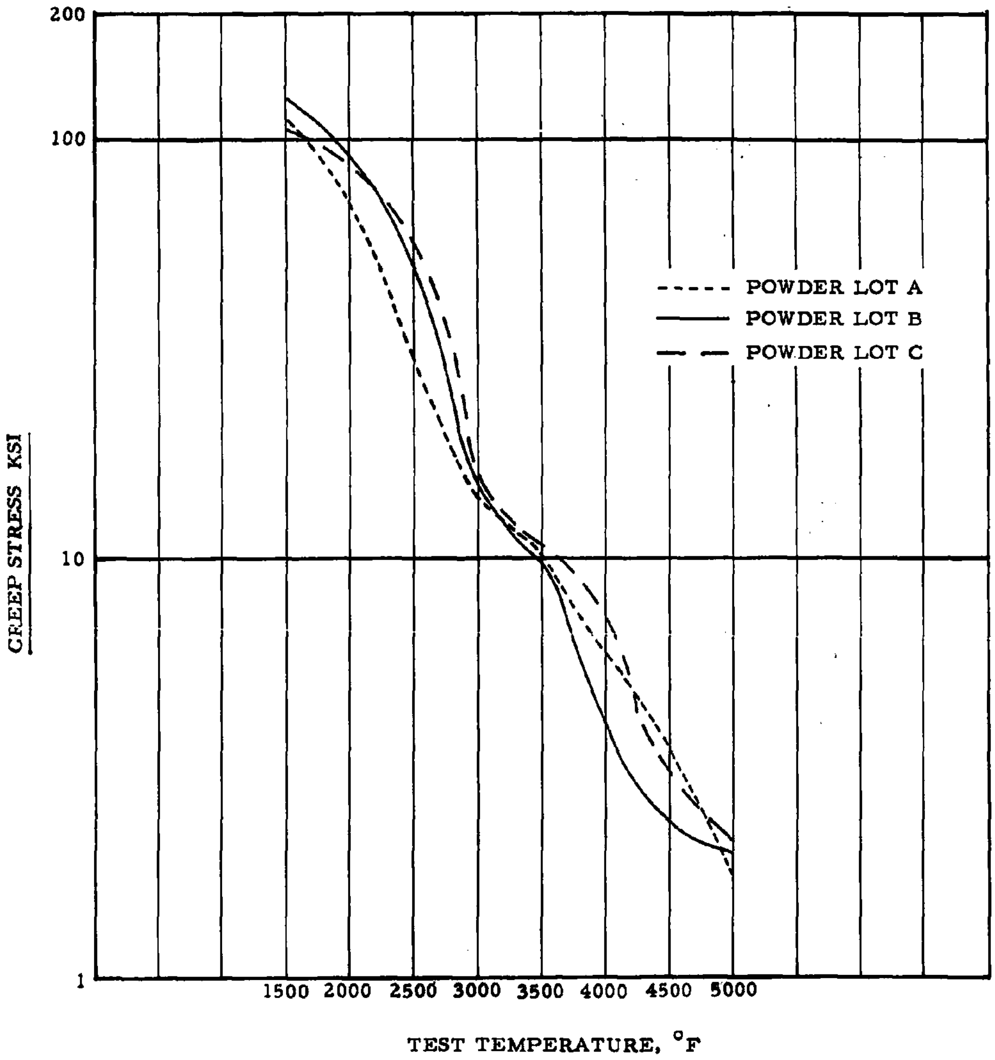


FIGURE 33. MINIMUM STRESS REQUIRED TO REACH 2% CREEP IN 3600 SECONDS AT TEMPERATURES FROM 1500 TO 5000°F

One or two measurements taken on each test specimen

Rockwell A Scale

Specimen Number	Readings		Specimen Number	Readings		Specimen Number	Readings	
BA-1	74.0	74.0	BA-40	72.5	71.5	BA-79	73.0	
BA-2	73.0	73.0	BA-41	74.0	73.5	BA-80	73.5	
BA-3	74.0	73.0	BA-42	72.5	72.0	BA-81	74.0	
BA-4	72.0	73.0	BA-43	73.0	74.0	BA-82	73.5	
BA-5	73.5	74.0	BA-44	74.0	73.5	BA-83	74.0	
BA-6	73.5	73.5	BA-45	72.5	72.0	BA-84	74.0	
BA-7	73.0	74.0	BA-46	74.0	73.5	BA-85	73.0	
BA-8	72.5	73.0	BA-47	72.5	71.5	BA-86	74.0	
BA-9	73.5	73.5	BA-48	74.0	73.5	BA-87	73.0	
BA-10	74.5	74.0	BA-49	73.5	73.0	BA-88	72.5	
BA-11	75.0	74.0	BA-50	73.0	74.0	BA-89	74.0	
BA-12	73.5	73.0	BA-51	72.5	73.0	BA-90	74.0	
BA-13	73.0	74.0	BA-52	74.0	73.0	BA-91	73.0	
BA-14	72.5	73.0	BA-53	72.5	72.5	BA-92	74.0	
BA-15	73.5	73.5	BA-54	72.0	74.0	BA-93	73.5	
BA-16	73.5	73.0	BA-55	74.5	73.5	BA-94	73.5	
BA-17	73.5	72.5	BA-56	74.5	74.0	BA-95	73.5	
BA-18	71.5	72.0	BA-57	74.0	74.5	BA-96	73.5	
BA-19	73.5	73.0	BA-58	73.0	74.5	BA-97	73.5	
BA-20	73.0	72.5	BA-59	74.5	73.0	BA-98	73.5	74.0
BA-21	73.0	73.5	BA-60	73.0	73.5	BA-99	74.0	73.5
BA-22	73.0	73.0	BA-61	73.0		BA-100	73.5	74.0
BA-23	73.0	73.0	BA-62	74.0		BA-101	73.5	74.0
BA-24	72.0	73.0	BA-63	74.0		BA-102	73.0	73.0
BA-25	73.5	72.5	BA-64	73.0		BA-103	73.5	74.0
BA-26	73.5	73.0	BA-65	74.0		BA-104	74.0	73.5
BA-27	72.0	73.0	BA-66	73.0		BA-105	74.5	74.0
BA-28	72.0	73.5	BA-67	73.5		BA-106	73.5	73.5
BA-29	74.5	73.5	BA-68	74.0		BA-107	74.0	74.5
BA-30	72.5	73.0	BA-69	73.5		BA-108	74.0	74.0
BA-31	71.5	72.5	BA-70	73.5		BA-109	74.5	74.0
BA-32	72.0	71.5	BA-71	73.0		BA-110	74.0	74.0
BA-33	72.0	71.5	BA-72	74.0		BA-111	75.0	75.0
BA-34	72.5	73.5	BA-73	73.0		BA-112	73.5	74.0
BA-35	73.5	73.5	BA-74	74.0		BA-113	74.0	74.0
BA-36	74.0	73.0	BA-75	74.0		BA-114	74.0	74.0
BA-37	72.5	72.5	BA-76	73.0		BA-115	73.5	74.0
BA-38	73.0	73.5	BA-77	73.5		BA-116	73.0	74.0
BA-39	72.5	72.0	BA-78	73.5		BA-117	74.0	74.0

TABLE I (Continued)

HARDNESS MEASUREMENTS - POWDER LOT A

Specimen Number	Readings		Specimen Number	Readings		Specimen Number	Readings	
BA-118	73.5	74.0	BA-139	74.0	73.5	BA-159	74.5	74.5
BA-119	73.5	73.5	BA-140	72.5	73.0	BA-160	73.5	74.0
BA-120	74.5	74.0	BA-141	74.5	75.0	BA-161	73.0	73.5
BA-121	75.5	75.5	BA-142	74.0	74.0	BA-162	72.5	73.0
BA-122	74.0	74.0	BA-143	73.5	74.0	BA-163	73.0	73.0
BA-123	73.5	73.5	BA-144	74.0	73.5	BA-164	74.0	74.0
BA-124	73.5	-	BA-145	74.0	74.0	BA-165	74.5	74.0
BA-125	74.5	74.0	BA-146	75.5	75.5	BA-166	72.5	73.0
BA-126	74.5	74.0	BA-147	73.5	73.5	BA-167	73.5	74.0
BA-127	74.0	74.5	BA-148	73.0	73.5	BA-168	73.5	73.5
BA-128	74.0	74.0	BA-149	73.5	73.5	BA-169	74.0	73.5
BA-129	74.0	73.5	BA-150	74.0	73.5	BA-170	73.0	73.5
BA-130	73.0	73.0	BA-151	73.5	74.0	BA-171	73.0	72.5
BA-131	74.0	74.5	BA-152	74.0	73.5	BA-172	74.0	74.5
BA-132	74.5	74.5	BA-153	74.0	74.0	BA-173	73.0	73.0
BA-133	73.5	73.5	BA-154	74.5	74.0	BA-174	73.0	73.0
BA-134	74.0	73.5	BA-155	74.0	74.0	BA-175	74.0	73.5
BA-135	73.5	73.5	BA-156	73.5	74.0	BA-176	73.5	73.5
BA-136	74.0	74.0	BA-157	74.0	74.5	BA-177	74.5	74.0
BA-137	73.5	74.0	BA-158	74.5	74.5	BA-178	73.5	73.5
BA-138	73.0	72.5						

TABLE II

HARDNESS MEASUREMENTS - POWDER LOT B

One or two measurements taken on each test specimen

Rockwell A Scale

Specimen Number	Readings		Specimen Number	Readings		Specimen Number	Readings
BB-1	75.0	75.0	BB-41	76.0	76.0	BB-81	74.5
BB-2	74.5	74.5	BB-42	74.5	74.0	BB-82	75.0
BB-3	74.0	74.5	BB-43	75.5	75.5	BB-83	75.0
BB-4	74.0	74.0	BB-44	75.5	75.5	BB-84	75.0
BB-5	74.5	75.0	BB-45	75.5	75.5	BB-85	74.5
BB-6	74.5	74.5	BB-46	74.0	74.0	BB-86	75.0
BB-7	74.5	75.0	BB-47	75.0	75.5	BB-87	75.0
BB-8	74.0	74.0	BB-48	75.0	75.0	BB-88	74.0
BB-9	75.5	74.5	BB-49	75.5	76.0	BB-89	74.0
BB-10	75.0	75.5	BB-50	75.0	75.5	BB-90	74.5
BB-11	75.0	75.0	BB-51	75.0	75.5	BB-91	75.5
BB-12	75.0	75.5	BB-52	74.0	74.5	BB-92	74.5
BB-13	75.0	75.5	BB-53	74.0	74.0	BB-93	75.0
BB-14	74.5	75.0	BB-54	75.0	75.0	BB-94	74.5
BB-15	75.0	75.0	BB-55	74.5	75.0	BB-95	74.5
BB-16	75.0	75.0	BB-56	75.0		BB-96	73.5
BB-17	75.0	75.5	BB-57	74.0		BB-97	75.0
BB-18	74.0	75.0	BB-58	74.5		BB-98	75.0
BB-19	75.0	75.0	BB-59	74.0		BB-99	74.5
BB-20	75.0	75.5	BB-60	75.5		BB-100	74.5
BB-21	75.0	75.0	BB-61	74.0		BB-101	74.0
BB-22	75.0	75.0	BB-62	75.0		BB-102	74.5
BB-23	75.0	75.0	BB-63	74.5		BB-103	75.0
BB-24	75.0	75.0	BB-64	75.0		BB-104	74.0
BB-25	75.0	75.0	BB-65	74.5		BB-105	74.0
BB-26	75.0	75.5	BB-66	74.5		BB-106	75.5
BB-27	75.0	75.5	BB-67	74.0		BB-107	75.0
BB-28	74.5	74.5	BB-68	75.0		BB-108	74.0
BB-29	75.5	75.5	BB-69	74.5		BB-109	74.5
BB-30	74.5	75.0	BB-70	75.0		BB-110	74.5
BB-31	75.0	74.5	BB-71	74.0		BB-111	74.0
BB-32	75.5	75.5	BB-72	74.5		BB-112	74.0
BB-33	75.0	75.0	BB-73	74.5		BB-113	74.5
BB-34	75.0	75.0	BB-74	75.5		BB-114	73.5
BB-35	74.5	74.5	BB-75	75.0		BB-115	74.5
BB-36	75.5	76.0	BB-76	74.0		BB-116	74.5
BB-37	76.0	76.0	BB-77	75.0		BB-117	74.5
BB-38	74.5	75.0	BB-78	74.5		BB-118	74.0
BB-39	75.0	75.0	BB-79	75.0		BB-119	75.0
BB-40	75.0	75.0	BB-80	74.5		BB-120	74.5

TABLE II (Continued)

HARDNESS MEASUREMENTS - POWDER LOT B

Specimen Number	Readings	Specimen Number	Readings	Specimen Number	Readings	
BB-121	74.0	BB-137	73.0	BB-153	74.0	
BB-122	74.5	BB-138	74.5	BB-154	74.5	
BB-123	75.5	BB-139	74.0	BB-155	74.0	
BB-124	74.5	BB-140	75.0	BB-156	74.0	
BB-125	75.0	BB-141	74.0	BB-157	74.0	
BB-126	74.0	BB-142	75.0	BB-158	74.0	
BB-127	74.5	BB-143	75.0	BB-159	73.5	74.0
BB-128	75.0	BB-144	73.0	BB-160	75.0	
BB-129	73.5	BB-145	74.0	BB-161	74.5	75.0
BB-130	73.0	BB-146	75.0	BB-162	75.5	
BB-131	75.0	BB-147	74.5	BB-163	75.0	
BB-132	74.0	BB-148	74.0	BB-164	75.0	76.0
BB-133	75.5	BB-149	73.5	BB-165	75.0	74.5
BB-134	74.5	BB-150	74.5	BB-166	76.0	75.0
BB-135	74.0	BB-151	75.0	BB-167	74.0	75.0
BB-136	74.5	BB-152	73.5			

TABLE III

HARDNESS MEASUREMENTS - POWDER LOT C

One or two measurements taken on each test specimen

Rockwell A Scale

Specimen Number	Readings		Specimen Number	Readings		Specimen Number	Readings	
BC-1	73.5	74.5	BC-40	75.0		BC-79	73.5	74.0
BC-2	72.5	72.5	BC-41	73.5		BC-80	72.5	73.5
BC-3	74.5	74.0	BC-42	73.5		BC-81	73.0	73.0
BC-4	73.0	74.0	BC-43	73.5		BC-82	73.0	73.0
BC-5	73.0	73.5	BC-44	73.5		BC-83	73.0	74.0
BC-6	74.5	73.5	BC-45	73.0		BC-84	72.5	73.0
BC-7	74.0	73.5	BC-46	73.0		BC-85	73.5	73.5
BC-8	73.0	74.0	BC-47	74.0		BC-86	75.0	73.5
BC-9	73.0	73.5	BC-48	73.0		BC-87	72.5	73.5
BC-10	72.5	74.0	BC-49	74.0		BC-88	73.5	74.0
BC-11	73.5	74.5	BC-50	72.0	73.0	BC-89	73.0	71.5
BC-12	74.0	74.0	BC-51	73.0			75.0	74.5
BC-13	73.0	74.0	BC-52	72.0	72.0	BC-90	74.0	73.0
BC-14	75.0	74.5	BC-53	72.5		BC-91	74.5	72.5
BC-15	73.0	74.0	BC-54	73.0		BC-92	73.5	73.0
BC-16	73.0	73.5	BC-55	73.0		BC-93	73.0	75.5
BC-17	73.5	74.0	BC-56	74.0		BC-94	72.5	74.0
BC-18	74.0	74.0	BC-57	73.5		BC-95	72.5	73.0
BC-19	74.0	73.0	BC-58	72.0	73.5	BC-96	73.5	74.0
BC-20	74.0	73.5	BC-59	73.5		BC-97	73.0	73.5
BC-21	73.0	72.0	BC-60	74.0		BC-98	73.5	73.5
BC-22	73.5	73.5	BC-61	72.5		BC-99	73.5	74.0
BC-23	73.0	74.0	BC-62	73.0		BC-100	73.5	74.0
BC-24	73.5	73.5	BC-63	73.5		BC-101	74.0	73.0
BC-25	73.5		BC-64	73.0		BC-102	73.5	73.5
BC-26	73.0		BC-65	73.0	73.5	BC-103	73.0	73.5
BC-27	72.0	73.0	BC-66	73.5	74.0	BC-104	73.5	72.5
BC-28	72.0	71.5	BC-67	73.0	72.5	BC-105	73.0	73.0
BC-29	73.5		BC-68	73.5	74.0	BC-106	73.5	73.5
BC-30	73.5		BC-69	73.0	74.0	BC-107	73.0	72.5
BC-31	73.5		BC-70	74.0	73.0	BC-108	73.0	74.0
BC-32	73.5		BC-71	73.0	73.5	BC-109	72.5	74.0
BC-33	74.5		BC-72	73.0	72.5	BC-110	73.5	73.5
BC-34	72.5		BC-73	72.5	72.5	BC-111	73.5	74.0
BC-35	74.0		BC-74	73.0	73.0	BC-112	73.0	73.5
BC-36	73.5		BC-75	73.0	73.0	BC-113	72.5	74.0
BC-37	73.5		BC-76	72.0	73.0	BC-114	74.0	73.5
BC-38	73.0		BC-77	73.5	73.0	BC-115	73.0	73.5
BC-39	73.5		BC-78	72.5	74.0	BC-116	73.5	73.5

TABLE III (Continued)

HARDNESS MEASUREMENTS - POWDER LOT C

Specimen Number	Readings		Specimen Number	Readings		Specimen Number	Readings	
BC-117	73.0	73.5	BC-135	73.5	73.0	BC-153	73.0	74.0
BC-118	73.0	73.0	BC-136	74.0	74.0	BC-154	73.5	73.5
BC-119	73.5	75.0	BC-137	73.0	74.0	BC-155	73.0	73.0
BC-120	74.5	73.5	BC-138	74.0	74.0	BC-156	74.C	74.5
BC-121	74.5	73.5	BC-139	73.5	73.5	BC-157	74.0	74.0
BC-122	73.5	74.0	BC-140	73.0	73.0	BC-158	74.0	73.5
BC-123	75.0	74.5	BC-141	74.0	73.5	BC-159	73.0	73.0
BC-124	73.5	73.5	BC-142	73.5	74.0	BC-160	73.5	74.5
BC-125	72.5	72.5	BC-143	73.0	74.0	BC-161	73.0	73.5
BC-126	73.0	73.0	BC-144	73.0	73.0	BC-162	73.0	73.5
BC-127	73.5	73.0	BC-145	73.0	72.5	BC-163	74.0	73.0
BC-128	73.5	73.5	BC-146	73.0	73.0	BC-164	74.0	73.0
BC-129	72.5	73.5	BC-147	73.0	73.0	BC-165	74.0	73.5
BC-130	72.5	73.0	BC-148	72.5	73.0	BC-166	73.5	73.5
BC-131	73.0	72.5	BC-149	73.5	75.0	BC-167	74.0	73.0
BC-132	72.5	74.0	BC-150	73.0	74.5	BC-168	73.5	74.0
BC-133	73.0	73.0	BC-151	72.5	72.5	BC-169	73.0	74.0
BC-134	73.0	74.5	BC-152	73.0	73.5			

TABLE IV

1500°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot A

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time To Rupture (sec.)	Elongation in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BA-83	115.0	0.0073	0.8	-	-	-	-	-	-	-	3.5	4.0
BA-177	112.5	0.0072	0.4	-	4.5	9.4	15.0	-	-	-	19.0	3.5
BA-132	110.0	0.0071	0.50	0.16	13.0	38.0	135.0	-	-	-	145.0	3.5
BA-82	110.0	0.0071	0.53	0.15	12.0	36.0	128.0	-	-	-	202.0	3.5
BA-84	105.0	0.0070	0.45	0.16	25.0	95.0	490.0	820.0	-	-	885.0	3.5
BA-131	105.0	0.0069	0.43	0.13	20.0	62.0	310.0	-	-	-	340.0	3.0
BA-136	105.0	0.0070	0.48	0.17	10.0	46.0	301.0	544.0	-	-	547.0	4.0
BA-85	100.0	0.0075	-	-	-	-	-	-	-	-	-	-
BA-86	100.0	0.0068	0.35	0.08	60.0	240.0	2160.0	4235.0	-	-	4570.0	4.0
BA-81	95.0	0.0073	0.3	0.08	50.0	345.0	5400.0	-	-	-	11300.0	3.5

TABLE V

2000°F CREEP-RUPTURE PROPERTIES FOR COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot A

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain 0.1%	0.2%	0.5%	1.0%	2.0%	4.0%	Time To Rupture (sec.)	Elongation in 2 in. (%)
BA-87	88.0	0.0095	0.4	0.5	4.0	10.0	30.0	37.0	-	-	42.0	3.5
BA-88	80.0	0.0089	-	-	-	-	-	-	-	-	-	-
BA-89	80.0	0.0094	0.25	0.18	18.0	60.0	135.0	195.0	-	-	205.0	3.5
BA-138	80.0	0.0096	0.30	-	-	-	-	-	-	-	4.0	3.5
BA-178	80.0	0.0097	0.30	0.5	4.0	10.0	30.0	-	-	-	34.0	3.0
BA-169	75.0	0.0095	0.30	-	-	-	-	-	-	-	7.0	4.0
BA-176	75.0	0.0092	0.35	-	2.0	5.0	8.0	-	-	-	12.0	3.0
BA-159	75.0	0.0097	0.25	0.18	12.0	58.0	217.0	335.0	-	-	372.0	4.0
BA-174	75.0	0.0092	0.40	-	1.0	3.5	6.0	-	-	-	10.0	3.5
BA-160	70.0	0.0098	0.2	0.08	90.0	265.0	1020.0	1680.0	-	-	2120.0	4.0
BA-135	70.0	0.0102	0.35	0.3	-	8.0	21.0	50.0	-	-	69.0	4.0
BA-161	65.0	0.01	0.25	0.15	20.0	65.0	140.0	-	-	-	152.0	3.5
BA-134	65.0	0.0098	0.25	0.10	32.0	91.0	252.0	346.0	-	-	353.0	3.5
BA-162	65.0	0.0094	0.2	0.10	35.0	95.0	380.0	750.0	-	-	798.0	3.0
BA-137	65.0	0.0098	0.2	0.10	33.0	134.0	520.0	944.0	-	-	1001.0	4.5
BA-163	62.0	0.01	0.2	0.1	40.0	92.0	360.0	540.0	-	-	555.0	3.0
BA-175	60.0	0.0094	0.18	0.05	97.0	428.0	2030.0	3600.0	-	-	3830.0	4.0

TABLE VI

2500°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot A

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time To Rupture (sec.)	Elongation in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BA-133	30.0	0.0126	0.08	0.1	30.0	78.0	180.0	201.0	214.0	219.0	221.0	5.5
BA-165	29.0	0.0060	0.15	0.21	12.0	29.0	67.0	105.0	185.0	-	310.0	7.0
BA-170	27.0	0.013	0.10	0.15	20.0	37.0	52.0	66.0	81.0	92.0	95.0	5.5
BA-112	27.0	0.0129	0.10	0.6	8.4	16.0	27.0	38.0	51.0	58.0	60.0	6.0
BA-167	27.0	0.0129	0.08	0.08	130.0	332.0	505.0	565.0	622.0	667.0	670.0	6.5
BA-95	25.0	0.005	0.12	0.32	14.0	21.0	42.0	61.0	84.0	93.0	94.0	-
BA-94	25.0	0.01	0.11	0.05	350.0	627.0	900.0	1257.0	1803.0	2175.0	2560.0	9.0
BA-97	23.0	0.005	0.04	0.04	1620.0	3285.0	4980.0	6740.0	9600.0	14400.0	16150.0	10.0
BA-130	23.0	0.0128	0.05	0.06	85.0	201.0	305.0	340.0	392.0	473.0	517.0	10.0
BA-93	21.0	-	0.60	-	4.0	13.0	84.0	655.0	2070.0	9415.0	23000.0	12.0
BA-96	21.0	0.005	0.03	0.01	820.0	1200.0	1830.0	2955.0	4860.0	6240.0	6290.0	11.0

TABLE VII

3000°F CREEP-RUPTURE PROPERTIES FOR COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot A

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Thermal Exp. (in/in)	Load Strain (%)	Creep In 30 Sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time To Rupture (sec.)	Elong. in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BA-2	14.5	0.0165	1.0	2.3	-	0.5	1.0	6.0	23.0	81.0	290.0	21.0
BA-3	14.5	0.0156	0.15	0.62	3.0	7.5	23.0	54.0	122.0	271.0	640.0	16.0
BA-4	14.5	0.0152	0.45	1.07	1.0	2.0	8.5	27.0	85.0	255.0	771.0	19.0
BA-5	12.0	0.0148	0.14	0.3	7.5	17.5	65.0	173.0	490.0	1247.0	2441.0	12.0
BA-7	12.0	0.0149	0.25	0.46	3.0	8.0	35.0	110.0	363.0	980.0	2140.0	15.0
BA-10	12.0	0.020	0.19	0.36	5.0	13.0	47.0	132.0	390.0	1065.0	2406.0	14.0
BA-1	10.0	0.0154	0.1	0.2	8.0	30.0	139.0	460.0	1525.0	3843.0	7017.0	13.0
BA-8	10.0	0.0159	0.3	0.4	3.5	10.0	44.0	160.0	565.0	1783.0	6765.0	18.0
BA-9	10.0	0.0156	0.1	0.25	6.0	18.0	105.0	390.0	1220.0	3275.0	7471.0	13.0
BA-6	8.5	0.0155	0.05	0.1	30.0	95.0	467.0	1430.0	4260.0	9270.0	15807.0	14.0
BA-142	6.9	0.0167	0.03	0.03	205.0	548.0	2030.0	4500.0	9480.0	16320.0	23550.0	8.0

TABLE VIII

3500°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot A

Test Conditions:

Machine	- ETTM
Method of Heating	- Resistance
Gage Length	- 2.0 inches
Sheet Thickness	- 0.050 inch
Atmosphere	- Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain 0.1%	0.2%	0.5%	1.0%	2.0%	4.0%	Time To Rupture (sec.)	Elongation in 2 in. (%)
BA-11	12.0	0.0198	1.0	3.7	-	0.5	1.5	4.0	11.0	33.0	124.0	20.0
BA-12	12.0	0.0199	1.0	2.0	-	0.5	1.5	3.0	10.0	30.0	125.0	20.0
BA-13	12.0	0.0194	1.0	5.8	-	-	1.0	2.5	8.0	23.0	90.0	19.0
BA-14	10.0	0.0211	1.0	2.9	-	0.5	1.6	5.0	15.0	50.0	210.0	18.0
BA-15	10.0	0.0193	0.5	2.0	0.5	1.0	3.0	10.0	30.0	88.0	292.0	18.0
BA-16	10.0	0.0195	0.5	1.9	0.3	0.8	3.0	10.0	34.0	94.0	284.0	16.0
BA-17	8.0	0.0198	0.25	0.8	1.0	3.0	13.5	44.0	138.0	362.0	808.0	14.0
BA-20	8.0	0.0192	0.15	0.5	2.5	6.5	29.0	82.0	220.0	503.0	1042.0	15.0
BA-36	8.0	0.0205	0.20	0.51	3.0	8.0	29.0	85.0	230.0	527.0	1164.0	16.0
BA-38	5.5	0.0191	0.01	0.12	25.0	55.0	190.0	516.0	1275.0	2808.0	4820.0	12.0
BA-42	5.5	0.0198	0.1	0.2	10.0	30.0	155.0	465.0	-	-	-	-
BA-41	5.0	0.0188	0.01	0.04	190.0	462.0	1537.0	3537.0	7497.0	13977.0	-	-
BA-35	4.5	0.0192	0.01	0.015	480.0	1080.0	3085.0	6790.0	13740.0	25003.0	-	-

TABLE IX

4000°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot A

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time To Rupture (sec.)	Elongation in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BA-51	6.0	0.0235	0.45	2.13	0.5	1.3	4.0	11.0	28.0	67.0	111.0	14.0
BA-52	6.0	0.0233	0.25	1.04	1.5	3.5	11.0	28.0	63.0	128.0	315.0	23.0
BA-53	6.0	0.0216	0.50	2.0	0.3	1.2	4.5	12.0	30.0	69.0	198.0	20.0
BA-57	5.5	0.021	0.07	0.24	10.0	24.0	83.0	175.0	372.0	700.0	1290.0	22.0
BA-44	5.0	0.022	0.1	0.47	4.0	10.0	32.0	72.0	153.0	290.0	360.0	14.0
BA-45	5.0	0.0232	0.25	0.85	2.0	5.0	16.0	40.0	98.0	204.0	404.0	20.0
BA-46	5.0	0.0239	0.06	0.27	7.5	17.0	50.0	101.0	190.0	334.0	491.0	17.0
BA-47	4.0	0.0236	0.015	0.085	38.0	95.0	325.0	645.0	1165.0	1457.0	1871.0	10.0
BA-48	4.0	0.0235	0.01	0.04	90.0	205.0	535.0	1105.0	1800.0	1910.0	2209.0	14.0
BA-54	3.8	0.0225	0.015	0.045	96.0	210.0	578.0	1040.0	2075.0	2215.0	2254.0	17.0
BA-55	3.75	0.0218	0.02	0.04	94.0	215.0	630.0	1395.0	2745.0	2840.0	2947.0	18.0
BA-56	3.75	0.022	0.01	0.05	90.0	205.0	622.0	1282.0	2490.0	2555.0	2740.0	16.0

TABLE X

4500°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot A

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time To Rupture (sec.)	Elongation in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BA-53	4.0	0.0258	-	-	-	-	-	-	-	-	1.0	-
BA-164	3.5	0.021	-	-	-	-	1.0	1.8	3.0	6.0	8.5	13.0
BA-59	3.25	0.0275	0.04	0.72	4.5	9.0	22.0	40.0	54.0	73.0	78.0	13.0
BA-67	3.25	0.0254	0.05	0.48	6.0	12.0	32.0	64.0	120.0	194.0	298.0	15.0
BA-61	2.9	0.0256	0.1	0.7	2.0	6.0	20.0	44.0	66.0	74.0	91.0	16.0
BA-64	2.9	0.0241	0.075	0.32	6.0	15.0	55.0	133.0	206.0	233.0	262.0	14.0
BA-62	2.5	0.0248	0	0.09	35.0	85.0	230.0	321.0	330.0	336.0	362.0	19.0
BA-65	2.5	0.0248	0.05	0.45	6.5	14.5	32.0	52.0	86.0	150.0	377.0	16.0
BA-71	2.25	0.0236	0.015	0.015	314.0	545.0	730.0	972.0	1239.0	1818.0	2911.0	-
BA-68	2.25	0.023	0.005	0.02	375.0	840.0	1575.0	1590.0	1611.0	1666.0	1900.0	21.0
BA-63	2.0	0.025	0	0.015	285.0	625.0	710.0	730.0	770.0	854.0	1247.0	25.0
BA-66	2.0	0.0253	0.1	0.035	160.0	320.0	725.0	802.0	855.0	980.0	1266.0	10.0
BA-69	1.8	0.0256	0.01	0.1	30.0	60.0	205.0	320.0	363.0	493.0	801.0	-
BA-70	1.8	0.0249	0.01	0.02	215.0	345.0	405.0	489.0	632.0	974.0	2015.0	16.0
BA-171	1.5	0.0228	0.15	0.16	4.0	240.0	896.0	1420.0	2946.0	-	-	-

TABLE XI

5000°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot A

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain 0.1%	0.2%	0.5%	1.0%	2.0%	4.0%	Time To Rupture (sec.)	Elongation in 2 in. (%)
BA-72	1.7	0.0302	1.5	5.6	-	-	1.0	3.0	9.0	21.5	39.0	15.0
BA-74	1.55	0.030	0.005	0.35	8.0	17.0	36.0	42.0	51.0	67.0	95.0	16.0
BA-78	1.55	0.025	0.04	0.21	10.5	27.0	72.0	115.0	179.0	271.0	679.0	20.0
BA-79	1.55	0.025	0.05	0.15	16.0	41.0	122.0	192.0	225.0	274.0	438.0	18.0
BA-76	1.4	0.028	0.5	2.7	1.2	2.4	7.0	14.0	23.5	43.0	99.0	15.0
BA-77	1.4	0.027	0.01	0.005	160.0	303.0	445.0	487.0	536.0	595.0	615.0	10.0
BA-75	1.3	0.0280	0.005	0.005	227.0	337.0	430.0	490.0	585.0	723.0	900.0	12.0
BA-80	1.3	0.027	0.15	0.23	7.0	23.0	180.0	512.0	857.0	1344.0	2329.0	-
BA-73	1.0	0.0292	0.005	0.005	1140.0	1600.0	1843.0	2072.0	2255.0	3180.0	5150.0	14.0
BA-91	1.0	0.0244	0.000	0.001	1120.0	-	1360.0	1590.0	2103.0	4177.0	8179.0	10.0

TABLE XII

1500°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot B

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time To Rupture (sec.)	Elongation in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BB-149	130.0	0.0065	0.6	-	-	-	2.5	4.0	-	-	7.0	3.0
BB-148	125.0	0.007	0.5	0.3	5.0	28.0	155.0	302.0	-	-	305.0	4.0
BB-123	125.0	0.0065	0.4	0.4	15.0	32.0	420.0	1050.0	-	-	1115.0	3.5
BB-124	125.0	0.0068	0.4	0.14	19.0	91.0	615.0	1480.0	-	-	1745.0	4.0
BB-150	122.5	0.0069	0.5	0.35	4.5	11.0	65.0	133.0	-	-	140.0	3.0
BB-147	120.0	0.0068	0.4	0.2	12.0	65.0	455.0	950.0	-	-	1020.0	4.5
BB-151	117.5	0.007	0.45	0.2	9.0	30.0	180.0	490.0	-	-	502.0	3.0
BB-146	115.0	0.007	0.35	0.13	28.0	92.0	1230.0	3410.0	-	-	4540.0	4.0

TABLE XIII

2000°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot B

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time To Rupture (sec.)	Elongation in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BB-152	93.0	0.0094	0.4	0.3	6.0	15.0	53.0	84.0	-	-	92.0	4.0
BB-153	88.0	0.0098	0.35	-	-	-	-	-	-	-	6.0	4.0
BB-157	85.0	0.0099	0.3	0.45	4.0	11.0	36.0	-	-	-	61.0	3.5
BB-154	80.0	0.0094	0.23	0.08	38.0	70.0	130.0	175.0	-	-	185.0	4.5
BB-155	75.0	0.0095	0.25	0.25	17.0	48.0	205.0	312.0	-	-	321.0	3.5
BB-60	70.0	0.01	0.2	0.08	45.0	142.0	482.0	838.0	-	-	888.0	4.0
BB-156	60.0	0.0093	0.15	0.04	120.0	390.0	2310.0	6405.0	-	-	8742.0	4.5

TABLE XIV

2500°F CREEP-RUPTURE PROPERTIES FOR COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot B

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain 0.1%	0.2%	0.5%	1.0%	2.0%	4.0%	Time To Rupture (sec.)	Elongation in 2 in. (%)
BB-130	31.0	0.0080	0.3	-	0.2	0.3	0.6	1.2	2.0	9.0	28.0	9.0
BB-83	31.0	0.0135	1.0	-	-	-	-	0.5	1.0	2.0	12.0	12.0
BB-133	30.0	0.0125	0.1	0.07	56.0	138.0	246.0	301.0	345.0	381.0	392.0	10.0
BB-134	30.0	0.0126	0.1	0.05	71.0	165.0	285.0	336.0	392.0	467.0	480.0	10.0
BB-131	28.0	0.0070	0.05	0.02	465.0	1058.0	1585.0	1846.0	2129.0	2494.0	2520.0	9.0
BB-128	28.0	0.0096	0.1	0.1	30.0	63.0	122.0	165.0	248.0	417.0	429.0	9.0
BB-132	24.0	0.0102	0.05	0.02	300.0	600.0	910.0	1100.0	1415.0	1905.0	2235.0	10.0
BB-127	24.0	0.0098	0.055	0.05	246.0	390.0	555.0	722.0	1068.0	1840.0	3070.0	9.0
BB-126	22.0	0.0108	0.055	0.05	335.0	528.0	728.0	920.0	1355.0	2157.0	4116.0	13.0
BB-65	20.0	0.013	0.04	0.04	162.0	315.0	480.0	635.0	885.0	1325.0	1948.0	10.0
BB-56	20.0	0.0144	0.2	0.7	1.5	6.0	20.0	60.0	160.0	370.0	705.0	14.0
BB-64	20.0	0.013	0.05	0.05	200.0	377.0	578.0	695.0	1080.0	1790.0	2835.0	12.5
BB-129	20.0	0.011	0	0	785.0	955.0	1250.0	1713.0	2685.0	5120.0	15047.0	13.0
BB-120	18.0	0.0122	0.05	0.05	181.0	642.0	1150.0	1740.0	2565.0	4410.0	9050.0	14.0

TABLE XV

3000°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot B

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Thermal Exp. (in/in)	Load Strain (%)	Creep in 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time to Rupture (sec.)	Elong. in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BB-54	14.4	0.0148	0.6	1.3	0.8	1.7	8.3	32.0	61.0	155.0	318.0	13.5
BB-139	14.4	0.0154	0.65	1.5	0.4	1.0	5.5	16.0	51.0	129.0	356.0	12.5
BB-140	14.4	0.0160	0.8	1.8	0.5	1.5	5.0	14.0	39.0	100.0	257.0	13.0
BB-77	13.2	0.0158	0.6	1.0	2.0	3.8	11.5	34.0	89.0	223.0	515.0	14.0
BB-78	13.2	0.0150	0.5	0.9	1.9	4.0	18.0	40.0	105.0	255.0	570.0	13.0
BB-81	13.2	0.0150	0.6	0.95	1.5	3.5	13.0	33.0	95.0	247.0	535.0	14.0
BB-158	11.3	0.0165	0.3	0.6	1.0	4.0	21.0	75.0	195.0	788.0	1656.0	7.8
BB-159	11.3	0.0161	0.3	0.3	5.0	14.0	65.0	185.0	530.0	1220.0	1813.0	9.4
BB-163	11.3	0.0162	0.3	0.55	1.8	6.7	28.0	76.0	224.0	540.0	960.0	8.5
BB-95	9.2	0.0160	0.05	0.14	15.0	43.0	205.0	550.0	1260.0	2640.0	5283.0	8.2
BB-79	8.4	0.0159	0.03	0.1	27.0	90.0	345.0	930.0	Specimen cracked rewelding thermocouple			
BB-82	8.4	0.0159	0.04	0.1	30.0	80.0	370.0	950.0	2300.0	4550.0	6400.0	8.5

TABLE XVI

3500°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot B

Test Conditions:

Machine	- ETTM
Method of Heating	- Resistance
Gage Length	- 2.0 inches
Sheet Thickness	- 0.050 inch
Atmosphere	- Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Thermal Exp. (in/in)	Load Strain (%)	Creep in 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time to Rupture (sec.)	Elong. in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BB-89	9.2	0.0180	0.4	1.5	1.0	2.4	6.0	16.0	43.0	97.0	172.0	10.5
BB-90	9.2	0.0186	-	-	-	No Test	-	-	-	-	-	-
BB-91	9.2	0.0186	0.35	1.4	0.8	2.1	7.0	18.0	47.0	106.0	174.0	10.5
BB-160	7.5	0.0175	0.2	0.17	3.7	9.0	32.0	81.0	188.0	352.0	453.0	9.5
BB-161	7.5	0.0178	0.2	0.15	3.0	8.0	29.0	75.0	183.0	381.0	580.0	10.0
BB-162	7.5	0.0188	0.25	0.14	2.5	6.8	22.0	53.0	127.0	265.0	471.0	10.0
BB-86	6.0	0.0175	0.07	0.17	15.0	40.0	155.0	410.0	860.0	1462.0	1835.0	9.0
BB-87	6.0	0.0178	0.06	0.15	20.0	48.0	180.0	425.0	910.0	1524.0	1741.0	10.0
BB-88	6.0	0.0188	0.05	0.14	26.0	57.0	182.0	428.0	895.0	1525.0	1951.0	9.0
BB-93	5.4	0.0175	0.05	0.05	116.0	257.0	895.0	1935.0	3780.0	6275.0	8725.0	11.0
BB-94	5.4	0.021	0.04	0.05	70.0	165.0	535.0	1230.0	2450.0	4150.0	5300.0	12.0
BB-92	4.8	0.018	0.02	0.03	255.0	595.0	1830.0	3780.0	7450.0	11870.0	19800.0	10.0

TABLE XVII

4000°F CREEP-RUPTURE PROPERTIES FOR COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot B

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Thermal Exp. (in/in)	Load Strain (%)	Creep in 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time to Rupture (sec.)	Elong. in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BB-57	4.8	0.0238	0.4	2.1	0.4	1.0	3.5	10.0	28.0	70.0	136.0	8.5
BB-58	4.8	0.0230	0.6	2.7	0.1	0.4	3.0	8.0	20.0	48.0	89.0	11.0
BB-59	4.8	0.0225	0.1	0.2	13.0	36.0	85.0	164.0	290.0	447.0	517.0	10.0
BB-80	3.8	0.023	0.6	1.7	0.2	1.2	4.0	10.0	32.0	94.0	285.0	14.0
BB-84	3.8	0.0224	0.04	0.3	12.0	25.0	55.0	95.0	160.0	250.0	314.0	12.5
BB-143	3.8	0.0227	0.02	0.05	75.0	185.0	580.0	1120.0	2000.0	3030.0	4500.0	*
BB-85	3.2	0.0228	0.05	0.3	10.0	23.0	70.0	150.0	285.0	498.0	1412.0	12.0
BB-137	3.2	0.022	0.02	0.01	265.0	620.0	1800.0	3810.0	7100.0	11160.0	12470.0	8.5
BB-145	3.2	0.021	0.02	0.02	205.0	540.0	1620.0	3300.0	6200.0	*	8940.0	*
BB-74	2.4	0.0225	0.01	0.02	130.0	215.0	480.0	860.0	1560.0	1900.0	5550.0	15.0
BB-75	2.4	0.0224	0.02	0.05	76.0	180.0	520.0	1085.0	1960.0	3835.0	8622.0	19.0
BB-76	2.0	0.0225	0.02	0.06	85.0	230.0	840.0	1920.0	4380.0	*	10060.0	*

* Failed at Radius

TABLE XVIII

4500°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot B

Test Conditions:

Machine	- ETTM
Method of Heating	- Resistance
Gage Length	- 2.0 inches
Sheet Thickness	- 0.050 inch
Atmosphere	- Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain 0.1%	0.2%	0.5%	1.0%	2.0%	4.0%	Time To Rupture (sec.)	Elongation in 2 in. (%)
BB-66	3.0	0.0261	0.7	10.4	0.5	1.0	2.5	4.5	11.0	23.0	38.5	13.0
BB-67	3.0	0.0271	0.8	1.5	2.5	4.0	10.0	20.0	38.0	65.0	100.0	17.0
BB-68	3.0	0.0258	0.0	0.32	9.5	18.5	45.0	114.0	139.0	-	143.5	8.0
BB-135	2.36	0.0230	0.7	0.27	8.0	21.0	75.0	181.0	435.0	1090.0	1746.0	8.0
BB-69	2.36	0.0278	0.4	2.0	1.0	2.5	5.5	13.0	30.0	69.0	131.0	14.0
BB-121	2.36	0.0220	0.8	-	0.5	1.0	2.0	3.0	7.0	14.0	100.0	8.0*
BB-70	2.0	0.0262	0.0	0.035	200.0	460.0	1230.0	1730.0	3420.0	-	3704.0	5.5
BB-71	2.0	0.0271	0.015	0.12	26.0	41.0	104.0	180.0	602.0	427.0	432.0	9.5
BB-136	2.0	0.0245	0.05	0.13	19.0	62.0	254.0	659.0	1156.0	2089.0	2161.0	8.0*
BB-141	1.75	0.0222	0.01	0.02	549.0	1240.0	3180.0	6070.0	-	-	-	-
BB-72	1.5	0.0271	0.005	0.05	54.0	95.0	182.0	303.0	405.0	495.0	770.0	18.0
BB-73	1.5	0.0248	0.005	0.015	700.0	1620.0	-	3400.0	3570.0	3612.0	3720.0	15.0
BB-74	1.5	0.0232	0.0	0.0	530.0	1150.0	-	-	1830.0	2440.0	2899.0	19.0
BB-144	1.25	0.0215	0.0	0.1	4515.0	6240.0	7725.0	9600.0	17190.0	-	-	-
BB-121	1.25	0.0225	0.0	0.0	1510.0	1955.0	2410.0	3105.0	6120.0	8220.0	8280.0	-

* Failed at thermocouple weld

TABLE XIX

5000°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot B

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Thermal Exp. (in/in)	Load Strain (%)	Creep in 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time to Rupture (sec.)	Elong. in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BB-115	3.07	0.0318	2.0	-	-	0.5	1.0	2.0	3.0	-	18.0	17.0
BB-111	2.0	0.0310	0.0	0.4	5.0	13.0	38.0	73.0	115.0	114.0	151.0	6.0
BB-112	2.0	0.0283	1.6	0.75	2.0	5.5	20.0	40.0	62.0	-	81.0	6.0
BB-119	2.0	0.0322	1.6	0.35	1.3	3.0	8.0	16.0	32.0	56.0	73.5	7.0
BB-104	1.7	0.0332	0.0	0.105	29.0	63.0	145.0	227.0	277.0	287.0	288.0	3.0
BB-99	1.5	0.028	0.03	0.32	9.0	20.0	45.0	81.0	136.0	225.0	298.0	12.5
BB-100	1.5	0.026	0.0	0.05	78.0	163.0	337.0	479.0	562.0	565.0	567.0	5.0
BB-102	1.5	0.0305	0.25	2.6	1.5	3.0	7.0	12.0	22.0	50.0	131.0	14.0
BB-113	1.25	0.0303	0.0	0.035	135.0	234.0	575.0	830.0	980.0	1003.0	1004.0	2.0
BB-116	1.0	0.0301	0.0	0.04	180.0	540.0	1590.0	3120.0	4072.0	4162.0	4163.0	5.0
BB-117	1.0	0.0322	0.04	0.25	15.0	25.0	53.0	85.0	148.0	312.0	483.0	12.0
BB-118	1.0	0.0302	0.0	0.0	255.0	425.0	712.0	1275.0	1600.0	1602.0	1603.0	4.5

TABLE XX

1500°F CREEP-RUPTURE PROPERTIES FOR COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot C

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time To Rupture (sec.)	Elongation in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BC-58	106.0	0.0072	0.62	-	1.5	6.0	22.0	-	-	-	25.0	2.5
BC-59	103.0	0.0071	0.55	-	3.5	10.0	49.0	-	-	-	61.0	2.5
BC-57	100.0	0.0071	0.40	0.19	5.0	40.0	310.0	-	-	-	795.0	2.0
BC-65	98.0	-	-	-	Specimen Cracked Setting Up					-	-	-
BC-66	98.0	0.0074	0.45	0.20	8.0	32.0	320.0	-	-	-	506.0	3.0
BC-56	95.0	0.0074	0.30	0.14	7.0	170.0	1950.0	3740.0	-	-	3980.0	3.0
BC-108	95.0	0.0072	0.30	0.13	19.0	130.0	- Machine Malfunction				-	-
BC-109	95.0	0.0075	0.30	0.14	20.0	115.0	1295.0	3360.0	-	-	4450.0	3.5
BC-67	93.5	0.0072	0.45	0.30	6.0	20.0	100.0	178.0	-	-	180.0	3.5
BC-55	92.0	0.0078	0.25	0.09	38.0	260.0	2700.0	6000.0	-	-	7050.0	3.0

TABLE XXI

2000°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot C

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain 0.1%	0.2%	0.5%	1.0%	2.0%	4.0%	Time To Rupture (sec.)	Elongation in 2 in. (%)
BC-68	90.0	0.0104	0.35	-	3.0	7.5	20.0	29.5	30.0	-	32.0	3.5
BC-62	80.0	0.0093	0.40	0.26	7.0	23.0	72.0	109.0	111.0	-	115.0	4.5
BC-69	80.0	0.0103	0.35	0.30	15.0	31.0	71.0	81.5	82.5	-	86.0	3.5
BC-71	75.0	0.0105	0.25	0.17	20.0	56.0	210.0	395.0	418.0	-	420.0	3.5
BC-61	70.0	0.0095	0.23	0.10	28.0	148.0	790.0	1740.0	1966.0	-	1980.0	4.5
BC-74	70.0	0.0105	0.35	0.15	21.0	62.0	580.0	1300.0	1314.0	-	1365.0	4.0
BC-73	65.0	0.0100	0.20	0.05	67.0	240.0	630.0	2520.0	3898.0	-	3900.0	4.0

TABLE XXII

2500°F CREEP-RUPTURE PROPERTIES FOR COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot C

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Sheet Thickness - 0.050 inch
Gage Length - 2.0 inches
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain 0.1%	0.2%	0.5%	1.0%	2.0%	4.0%	Time To Rupture (sec.)	Elongation in 2 in. (%)
BC-99	45.0	0.013	0.25	1.0	6.0	15.0	27.0	31.0	34.0	-	36.0	5.0
BC-165	45.0	0.012	-	-	Failed in Radius Applying Stress					-	-	-
BC-168	45.0	0.0126	-	-	Machine Malfunction - No Test				-	-	-	-
BC-102	40.0	0.0132	0.15	0.18	14.0	34.0	92.0	145.0	162.0	164.0	166.0	5.5
BC-106	40.0	0.0123	0.15	0.15	20.0	44.0	103.0	119.0	128.0	131.0	135.0	5.0
BC-107	40.0	0.0121	0.15	0.13	19.0	55.0	110.0	127.0	130.0	136.0	138.0	5.5
BC-103	33.0	0.0125	0.08	0.06	58.0	145.0	304.0	320.0	338.0	351.0	372.0	5.5
BC-105	32.0	0.0125	0.08	0.10	40.0	120.0	295.0	368.0	390.0	402.0	406.0	5.0
BC-104	31.0	0.0123	0.07	0.05	75.0	240.0	630.0	785.0	874.0	936.0	940.0	5.5
BC-100	30.0	0.0131	0.08	0.05	96.0	243.0	Machine Malfunction			-	372.0	5.0
BC-101	30.0	0.0122	0.10	0.03	115.0	309.0	870.0	1102.0	1284.0	1363.0	1373.0	5.0
BC-63	27.5	0.0128	0.07	0.06	105.0	253.0	501.0	560.0	648.0	765.0	817.0	9.0
BC-64	27.5	0.0127	0.07	0.08	52.0	232.0	482.0	577.0	645.0	730.0	777.0	7.5

TABLE XXIII

3000°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot C

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time To Rupture (sec.)	Elongation in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BC-78	16.0	0.0140	1.0	1.45	1.0	2.0	6.0	19.0	62.0	205.0	2273.0	18.0
BC-79	16.0	0.0120	1.0	2.4	0.4	0.8	2.0	7.0	24.0	92.0	370.0	19.0
BC-80	16.0	0.0118	0.55	0.95	0.8	2.0	8.0	33.0	175.0	290.0	1070.0	15.0
BC-77	14.0	0.0135	0.45	0.83	1.0	3.0	14.0	41.0	141.0	426.0	763.0	10.0
BC-76	12.0	0.0135	0.35	0.43	4.0	8.0	40.0	128.0	392.0	1004.0	1886.0	11.0
BC-82	12.0	0.0164	0.40	0.60	2.0	5.0	24.0	84.0	300.0	909.0	1368.0	11.0
BC-83	12.0	0.0112	0.30	0.32	4.0	7.0	75.0	318.0	615.0	1460.0	3395.0	12.0
BC-75	10.0	0.0112	0.15	0.20	10.0	28.0	151.0	424.0	1158.0	2520.0	3830.0	8.0
BC-81	8.0	0.0150	0.03	0.12	22.0	80.0	510.0	1660.0	6030.0	*Machine malfunction 7600 sec.		
BC-84	8.0	0.0110	0.03	0.08	38.0	130.0	883.0	2900.0	8540.0	*Discontinued Test at 12,600 sec.		

TABLE XXIV

3500°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot C

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time To Rupture (sec.)	Elongation in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BC-88	10.0	0.0150	0.12	0.25	6.0	19.0	85.0	265.0	785.0	1920.0	2287.0	15.0
BC-89	10.0	0.0189	0.54	1.5	0.5	1.5	5.0	14.5	45.0	65.0	374.0	16.0
BC-90	10.0	0.0189	0.30	0.55	2.0	6.0	26.0	82.0	196.0	355.0	829.0	17.0
BC-92	9.0	0.0187	0.22	0.43	2.5	7.0	39.0	120.0	323.0	443.0	902.0	17.0
BC-94	9.0	0.0182	0.55	1.0	2.0	4.0	12.0	31.0	84.0	212.0	755.0	18.0
BC-95	9.0	0.0187	0.30	1.0	0.5	2.0	9.0	30.0	92.0	231.0	536.0	15.0
BC-85	8.0	0.0150	0.12	0.27	5.0	15.0	89.0	305.0	951.0	2410.0	4320.0	11.0
BC-91	8.0	0.0181	0.20	0.39	4.0	11.0	43.0	123.0	345.0	825.0	2167.0	20.0
BC-97	8.0	0.0186	0.14	0.35	6.0	15.0	52.0	155.0	418.0	930.0	945.0	7.0
BC-87	7.7	0.015	0.07	0.12	24.0	74.0	326.0	985.0	2790.0	6060.0	9205.0	13.0
BC-93	7.0	0.0185	0.10	0.20	14.0	30.0	236.0	507.0	936.0	1740.0	3519.0	-
BC-48	6.0	0.0182	0.04	0.04	78.0	157.0	525.0	1300.0	3150.0	7285.0	16005.0	15.0
BC-96	6.0	0.0173	0.03	0.06	60.0	175.0	700.0	1812.0	4240.0	8745.0	16121.0	18.0
BC-98	6.0	0.0178	0.05	0.14	19.0	96.0	420.0	1190.0	2760.0	5400.0	8975.0	10.5

TABLE XXV

4000°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot C

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time To Rupture (sec.)	Elongation in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BC-50	8.5	0.0225	0.80	3.8	0.25	0.75	2.0	4.5	12.5	32.0	105.0	19.0
BC-110	8.5	0.0221	0.80	2.7	0.50	1.0	3.0	7.5	20.0	48.0	155.0	20.0
BC-49	8.0	0.0229	0.40	1.4	1.0	2.0	6.0	18.0	51.0	130.0	400.0	19.0
BC-111	7.0	0.0218	0.60	1.5	1.0	2.0	7.0	18.0	42.5	100.0	233.0	18.0
BC-114	6.5	0.0223	0.30	1.3	1.0	2.0	8.0	21.0	58.5	172.0	474.0	18.0
BC-115	5.5	0.0212	0.15	0.48	4.0	10.0	34.0	79.0	197.0	410.0	872.0	18.0
BC-116	5.5	0.0215	0.15	0.54	3.0	8.0	27.0	68.5	160.0	341.0	705.0	18.0
BC-117	5.5	0.0216	0.10	0.33	6.0	15.0	52.0	127.0	290.0	585.0	840.0	13.0
BC-164	4.5	0.022	0.05	0.11	27.0	66.0	198.0	388.0	740.0	1250.0	1278.0	17.0
BC-167	4.5	0.022	0.02	0.15	17.5	45.0	145.0	330.0	701.0	1262.0	1313.0	14.0
BC-137	4.25	0.0220	0.015	0.09	40.0	92.0	280.0	634.0	1342.0	2220.0	2315.0	14.0
BC-136	4.0	0.0230	0.005	0.025	245.0	575.0	1475.0	3095.0	4828.0	4848.0	4998.0	17.0
BC-138	4.0	0.0202	0.015	0.04	110.0	300.0	975.0	2140.0	4341.0	7260.0	7323.0	13.0

TABLE XXVI

4500°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot C

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time To Rupture (sec.)	Elongation in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BC-139	4.0	0.0270	2.0	-	-	-	-	1.0	1.5	2.0	5.0	15.0
BC-140	3.0	0.0229	0.20	1.15	2.0	4.0	12.0	26.0	49.0	80.0	184.0	15.0
BC-141	3.0	0.0265	0.15	0.90	2.0	5.0	15.5	34.0	67.5	119.0	355.0	14.0
BC-147	3.0	0.0280	0.03	0.12	22.0	44.0	88.0	120.0	148.0	172.0	190.0	11.0
BC-143	2.2	0.0268	0.05	0.21	10.5	28.0	92.0	155.0	255.0	466.0	1000.0	16.0
BC-150	2.2	0.0272	0.005	0.035	115.0	197.0	309.0	418.0	573.0	850.0	1289.0	13.0
BC-142	2.0	0.0280	0.015	0.07	79.0	170.0	367.0	580.0	1020.0	2167.0	4007.0	15.0
BC-144	2.0	0.0279	0.05	0.44	3.0	9.5	36.0	67.0	110.0	185.0	308.0	12.0
BC-148	2.0	0.0275	0.01	0.15	20.0	42.5	121.0	278.0	538.0	1007.0	1524.0	12.0
BC-145	1.6	0.0281	0.005	0.02	152.0	320.0	545.0	631.0	1075.0	1983.0	5591.0	15.0
BC-146	1.5	0.0260	0.005	0.03	241.0	415.0	714.0	1020.0	1465.0	2520.0	8353.0	15.0
BC-151	1.5	0.0283	0.005	0.035	305.0	580.0	1103.0	1593.0	2335.0	4440.0	8407.0	12.0
BC-149	1.25	0.0277	0.025	0	1440.0	3270.0	11400.0	Discontinued when 0.5% reached.				

TABLE XXVII

5000°F CREEP-RUPTURE PROPERTIES FOR
COMMERCIALLY PURE-SINTERED TUNGSTEN SHEET (FANSTEEL)

Powder Lot C

Test Conditions:

Machine - ETTM
Method of Heating - Resistance
Gage Length - 2.0 inches
Sheet Thickness - 0.050 inch
Atmosphere - Argon-7% Hydrogen

Spec. No.	Stress (ksi)	Approx. Thermal Exp. (in/in)	Loading Strain (%)	Creep In 30 sec. (%)	Time (Seconds) To Produce Indicated Plastic Creep Strain						Time To Rupture (sec.)	Elongation in 2 in. (%)
					0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
BC-152	2.0	0.030	0.3	1.05	1.0	2.5	10.0	28.0	64.5	130.0	309.0	14.5
BC-153	2.0	0.0302	0.3	1.6	1.0	2.0	7.0	17.0	40.0	81.5	118.0	12.0
BC-154	2.0	0.0271	0.2	1.18	1.0	3.0	10.5	25.0	51.0	90.0	162.0	13.0
BC-157	1.75	0.0324	0.05	0.24	5.0	22.5	67.0	Failed outside gage length			68.0	-
BC-160	1.75	0.0290	0.005	0.20	14.5	31.0	77.0*	"	"	"	86.0	-
BC-163	1.75	0.0302	0.015	0.075	50.0	105.0	234.0	313.0	366.0	414.0	453.0	12.0
BC-155	1.5	0.0302	0.005	0.24	9.0	24.0	70.0	129.0	220.0	342.0	376.0	8.5
BC-158	1.5	0.0295	0.015	0.085	42.0	112.0	Failed outside gage length				137.0	-
BC-161	1.5	0.0285	0.01	0.20	15.0	30.0	73.5*	Failed outside gage length			648.0	-
BC-156	1.0	0.0297	0.005	0.03	312.0	720.0	1341.0	1795.0	2710.0	4317.0	5057.0	8.5
BC-159	1.0	0.030	0.005	0.05	115.0	396.0	1318.0	Failed outside gage length			1555.0	-
BC-162	1.0	0.030	0.005	0.005	545.0	1410.0	3787.0	4300.0	4775.0	5340.0		

* Extrapolated Point

TABLE XXVIII

STRESS REQUIRED TO REACH
2% CREEP IN 30, 120, 600, AND 3600 SECONDS

Powder Lot	Test Temperature (°F)	Stress (kpsi) To Reach 2% Creep*			
		30 Seconds	120 Seconds	60 Seconds	3600 Seconds
A	1500	111.5	107.5	103.0	98.0
	2000	69.0	65.0	62.0	60.0
	2500	29.0	24.5	22.5	20.0
	3000	14.0	12.0	10.0	7.7
	3500	10.0	8.1	6.2	5.0
	4000	5.9	4.9	4.2	3.6
	4500	(3.6)[1]	2.25	1.7	1.5
A	5000	1.6	1.45	1.30	(0.92)[1]
B	1500	127.0	123.0	117.0	115.0
	2000	90.0	80.0	71.5	63.0
	2500	-	(32.0)[1]	22.5	(17.0)[1]
	3000	15.0	12.0	10.0	(7.7)[1]
	3500	9.7	7.6	6.3	5.2
	4000	4.1	3.5	2.85	2.1
	4500	2.35	1.9	1.45	1.25
B	5000	2.0	1.5	1.25	(0.9)[1]
C	1500	105.0	101.0	98.0	93.0
	2000	(87.0)[1]	78.0	72.0	65.0
	2500	-	40.0	28.0	-
	3000	15.5	13.5	11.0	8.5
	3500	10.5	8.7	7.3	5.8
	4000	7.3	5.7	4.5	4.0
	4500	3.2	2.6	1.8	1.3
C	5000	(2.1)[1]	1.7	1.25	0.97

* The line on each creep graph indicating minimum stress to reach 2% creep has been used in making up this table.

( )[1] Extrapolated or interpolated.

TABLE XXIX

MECHANICAL PROPERTIES FOR COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot A | Test Condition 1

Machine - ETTM
Method Heating - Resistance
Hold Time at Temp.-5 min.(1000 to 2000°F Tests),
3 min.(2500 to 5000°F Tests)
Strain Rate to Y.S. - 0.005 in/min.

Strain Rate Y.S. to U.T.S. - 0.05 in/min.
Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Spec. No.	Test Temp. (°F)	Hold Time (min.)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)	Remarks
B[illegible]-119	R.T.	-	--	200.0	219.0	0.95	45.8	-	--
B[illegible]-1[illegible]1	R.T.	-	--	--	232.0	0.54	49.4	-	--
B[illegible]-139	R.T.	-	--	--	--	--	--	-	Cracked Loading
B[illegible]-144	1000	5	0.0042	90.0	99.1	3.2	42.0	51	--
B[illegible]-145	1000	5	0.0040	112.0	--	--	43.9	-	Failed at Grip
B[illegible]-146	1000	5	0.0038	141.0	161.5	3.5	44.1	20	--
B[illegible]-147	1500	5	0.0067	88.0	94.0	3.0	38.9	47	--
B[illegible]-148	1500	5	0.0065	102.0	114.0	3.5	37.6	43	--
B[illegible]-98	1500	5	0.0064	103.0	112.0	3.0	39.0	39	--
B[illegible]-99	2000	5	0.0087	65.4	73.8	4.0	37.0	91	--

TABLE XXX

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot A | Test Condition 1

Machine - ETTM
Method Heating - Resistance
Hold Time at Temp. - 5 min. (1000°-2000° Tests), 3 min. (2500°-5000° Tests)
Strain Rate to Y.S. - 0.005 in/min.
Strain Rate YS to UTS - 0.05 in/min.
Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Specimen Number	Test Temperature (°F)	Hold Time (min.)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BA-100	2000	5	0.0104	69.0	80.5	3.5	36.0	26
BA-101	2000	5	0.0104	73.5	84.0	3.5	36.5	67
BA-104	2500	3	-	Broke setting up test		-	-	-
BA-105	2500	3	0.0134	Heat overshot - no test		-	-	-
BA-106	2500	3	0.0136	35.1	37.0	4.5	34.5	88
BA-107	3000	3	0.0162	9.9	16.5	16.0	16.5	66
BA-108	3000	3	0.0163	9.5	16.3	17.0	16.3	68
BA-109	3000	3	0.0165	9.9	17.0	8.0 No Fracture	15.5	-
BA-22	3500	3	0.0186	5.5	9.9	20.0	10.7	47
BA-23	3500	3	0.0184	6.6	10.5	15.0	11.6	33
BA-24	3500	3	0.0192	5.2	8.8	17.0	12.6	58
BA-27	4000	3	0.0227	3.4	4.8	16.0	6.8	90
BA-28	4000	3	0.0225	4.0	6.0	17.0	8.0	37
BA-31	4000		0.0223	Specimen Cracked - No Test			-	-
BA-32	4500		0.0274	1.2	2.4	15.0	4.1	90
BA-37	4500		0.0262	1.4	2.8	14.0	3.8	26
BA-39	4500		0.0279	2.3	3.4	16.0	3.6	29
BA-40	5000		0.0303	1.1	1.5	7.5	2.6	21.5
BA-43	5000		0.0313	0.8	1.4	16.0	2.8	22
BA-50	5000		0.0315	0.8	1.4	16.0	-	-

TABLE XXXI

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot B — Test Condition 1

Machine - ETTM
Method Heating - Resistance
Hold Time At Temp. - 5 min.(1000 to 2000°F Tests), 3 min.(2500 to 5000°F Tests)
Strain Rate to Y.S.- 0.005 in/min.

Strain Rate Y.S. to U.T.S. - 0.05 in/min.
Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Specimen Number	Test Temperature (°F)	Hold Time (min.)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BB-1	R.T.	--	--	222.0	245.0	0.97	47.0	0
BB-2	R.T.	--	--	221.0	224.0	0.75	46.0	0
BB-3	R.T.	--	--	--	198.0*	--	44.0	0
BB-4	1000	5	0.0045	132.5	149.0	3.0	47.0	40
BB-5	1000	5	0.0046	137.5	150.5	4.5	43.0	38
BB-6	1000	5	0.0045	131.5	141.0	3.5	43.0	31
BB-15	1500	5	0.0069	114.0	129.0	3.5	37.0	33
BB-16	1500	5	0.0069	110.5	125.0	3.5	40.3	32
BB-17	1500	5	0.0070	111.0	130.0	3.5	42.0	30
BB-18	2000	5	0.0095	78.5	90.0	4.0	26.0	48
BB-19	2000	5	0.0093	79.3	93.0	4.5	34.7	72
BB-20	2000	5	0.0095	81.0	92.0	4.0	37.0	44
BB-21	2500	3	0.0129	28.3	30.8	9.5	18.5	86
BB-22	2500	3	0.0125	24.0	29.9	10.0	27.0	83
BB-44	2500	3	0.0128	40.0	42.0	6.5	32.0	92
BB-25	3000	3	0.0154	8.2	13.5	7.5	13.0	53
BB-26	3000	3	0.0156	10.5	18.0	15.0	11.7	53
BB-27	3000	3	0.0152	9.8	17.6	16.0	11.1	62

*Failed in radius prior to Y.S. 0.005 in/min. rate

TABLE XXXII

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot B

Test Condition 1

Machine - ETTM
Method Heating - Resistance
Hold Time At Temp. - 5 min.(1000 to 2000°F Tests),
3 min.(2500 to 5000°F Tests)
Strain Rate to YS - 0.005 in/min.

Strain Rate YS to UTS - 0.05 in/min.
Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Specimen Number	Test Temperature (°F)	Hold Time (min.)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BB-50	3500	3	0.0184	6.3	9.5	12.0	13.6	36
BB-51	3500	3	0.0192	7.0	10.2	12.0	12.0	31
BB-52	3500	3	0.0186	6.5	10.0	10.0	14.0	28
BB-106	4000	3	0.0238	5.0	6.9	9.0	8.2	20
BB-107	4000	3	0.0237	4.6	6.6	7.0	--	17
BB-108	4000	3	0.0230	4.6	6.5	8.0	7.6	25
BB-109	4500	3	0.0272	1.8	2.3	17.0	3.7	91
BB-110	4500	3	0.0270	1.9	2.6	9.0	2.6	12
BB-114	4500	3	0.0265	2.8	3.9	6.0	3.7	92
BB-165	5000	3	0.0267	(1.7)*	2.4	7.0	--	--
BB-166	5000	3	0.0270	(1.5)*	2.5	8.0	--	--
BB-164	5000	3	0.0260	-	3.4	7.0	--	--

* Extrapolated

TABLE XXXIII

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot C

Test Condition 1

Machine - ETTM
Method Heating - Resistance
Hold Time at Temp. - 5 min.(1000 to 2000°F Tests), 3 min.(2500 to 5000°F Tests)
Strain Rate to Y.S. - 0.005 in/min.

Strain Rate Y.S. to U.T.S. - 0.05 in/min.
Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Specimen Number	Test Temperature (°F)	Hold Time (min.)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BC-1	R.T.	-	-	-*	138.0*	-	48.5	-
BC-2	R.T.	-	-	-*	181.0*	-	48.0	-
BC-70	R.T.	-	-	-*	204.0*	-	46.1	-
		*Failed prior to Y.S. at 0.005 in/min.						
BC-3	1000	5	0.0047	105.0	122.0	4.0	39.5	26.0
BC-4	1000	5	0.0047	105.0	123.5	4.0	40.0	11.0
BC-5	1000	5	0.0047	103.5	121.5	4.5	40.5	36.0
BC-6	1500	5	0.0073	95.5	107.0	4.5	36.5	43.0
BC-11	1500	5	0.0075	89.5	102.5	4.0	38.5	35.0
BC-12	1500	5	0.0075	89.7	102.5	4.0	38.1	33.0
BC-17	2000	5	0.0107	73.0	83.0	4.5	34.0	91.0
BC-18	2000	5	0.0105	75.5	86.1	4.5	32.0	91.0
BC-19	2000	5	0.0106	78.0	89.8	4.5	31.5	91.0
BC-20	2500	3	0.0134	32.5	35.5	7.0	25.3	92.0
BC-21	2500	3	0.0138	32.5	35.5	7.0	26.0	92.0
BC-22	2500	3	0.0138	32.0	35.4	7.0	26.9	92.0
BC-43	3000	3	0.0158	9.3	16.2	18.0	16.4	62.0
BC-44	3000	3	0.0155	9.3	16.0	17.0	16.2	61.0
BC-45	3000	3	0.0156	8.0	16.3	18.0	16.0	69.0

(Continued)

TABLE XXXIV

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot C

Test Condition 1

Specimen Number	Test Temperature (°F)	Hold Time (min.)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BC-46	3500	3	0.0189	6.6	10.7	10.0	11.6	49.0
BC-47	3500	3	0.0185	6.6	11.1	20.0	11.6	51.0
BC-122	3500	3	0.0182	7.2	12.1	16.5	11.2	-
BC-123	4000	3	0.0223	4.4	7.0	8.0	8.3	-
BC-124	4000	3	0.0220	4.9	7.8	17.5	8.1	-
BC-125	4000	3	0.0215	5.1	7.7	15.0	7.6	-
BC-126	4500	3	0.0268	1.8	2.5	14.0	3.4	-
BC-127	4500	3	0.0270	2.1	3.4	8.5	3.8	-
BC-129	4500	3	0.0275	2.3	3.3	17.5	3.0	-
BC-130	5000	3	0.0272	1.3*	2.0	14.0	-	-
BC-131	5000	3	0.0274	1.6*	2.1	7.0	-	-
BC-133	5000	3	0.0272	-	1.7	13.5	-	-

*Extrapolated

TABLE XXXV

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Test Condition 2

Powder Lot A

Machine - ETTM
Method Heating - Resistance
Hold Time at Temp. - 5 min.(1000 to 2000°F Tests), 3 min.(2500 to 5000°F Tests)
Strain Rate to Y.S.- 0.05 in/min.

Strain Rate Y.S. to U.T.S. - 0.5 in/min.
Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Spec. No.	Test Temp. (°F)	Hold Time (min.)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)	Remarks
BA-123	R.T.	-	--	--	116.0*	--	46.0	0	*Broke outside gage length
BA-124	R.T.	-	--	219.3	224.5	0.55	46.8	0	--
BA-120	1000	5	0.0037	97.9	108.5	3.0	42.9	39	--
BA-122	1000	5	0.00425	106.0	122.0	3.2	42.7	54	--
BA-125	1500	5	0.0064	86.7	94.5	3.5	37.8	35	--
BA-126	1500	5	0.0063	105.0	119.0	2.5	36.0	55	--
BA-127	2000	5	0.0086	86.8	94.5	4.0	36.7	63	--
BA-128	2000	5	0.0091	86.3	94.8	4.0	31.4	71	--
BA-140	2500	3	0.0125	27.1	31.3	6.0	27.0	96	--
BA-141	2500	3	0.0116	51.3	56.0	4.0	30.4	96	--
BA-142	3000	3	0.0169	6.8	13.6	6.5	16.2	9.8	--
BA-143	3000	3	0.0158	7.0	16.8	22.0	19.9	97	--

TABLE XXXVI

MECHANICAL PROPERTIES FOR COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot A | Test Condition 2

Machine - ETTM
Method Heating - Resistance
Hold Time at Temp. - 5 min.(1000 to 2000°F Tests), 3 min.(2500 to 5000°F Tests)
Strain Rate to YS - 0.05 in/min.

Strain Rate YS to UTS - 0.5 in/min.
Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Specimen Number	Test Temperature (°F)	Hold Time (min.)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BA-155	3500	3	0.0191	7.6	14.0	18.0	10.1	63
BA-156	3500	3	0.0182	6.6	12.6	19.0	12.1	50
BA-157	4000	3	0.0226	4.7	8.0	18.0	8.3	48
BA-158	4000	3	0.0225	5.8	9.5	20.0	7.9	60
BA-30	4500	3	0.0278	3.1	4.8	29.0	5.2	92
BA-25	4500	3	0.0273	2.7	4.0	10.0	4.3	82
BA-26	5000	3	0.0298	2.2	3.4	11.5	4.3	91
BA-29	5000	3	0.0302	1.2	3.1	13.0	1.2	91

TABLE XXXVII

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot B

Test Condition 2

Machine - ETTM
Method Heating - Resistance
Hold Time at Temp. - 5 min.(1000 to 2000°F Tests), 3 min.(2500 to 5000°F Tests)
Strain Rate to Y.S. - 0.05 in/min.

Strain Rate Y.S. to U.T.S. - 0.5 in/min.
Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Specimen Number	Test Temperature (°F)	Hold Time (min.)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BB-7	R.T.	-	--	239.0	259.5	1.0	46.5	-
BB-8	R.T.	-	--	--*	(242.0)*	0.6	49.0	-
BB-9	1000	5	0.0046	140.5	157.0	3.0	43.5	39
BB-10	1000	5	0.0047	138.0	156.0	3.5	42.5	31
BB-11	1500	5	0.0069	120.0	133.5	3.0	40.0	49
BB-12	1500	5	0.00685	112.0	126.5	2.0	40.0	39
BB-13	2000	5	0.0095	91.0	99.7	3.5	32.0	57
BB-14	2000	5	0.0094	91.0	100.3	4.5	33.0	59
BB-23	2500	3	0.0130	--	Bad Thermocouple - Test Not Valid			-
BB-24	2500	3	0.0118	17.1	30.9	15.0	23.0	84
BB-33	3000	3	0.0152	11.3	21.9	16.5	12.1	84.5
BB-34	3000	3	0.0157	11.2	22.2	18.0	14.0	83.0

* Failed prior to Y.S. at 0.05 in/min. rate.

TABLE XXXVIII

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot B

Test Condition 2

Machine - ETTM
Method Heating - Resistance
Hold Time at Temp. - 5 min.(1000 to 2000°F Tests), 3 min.(2500 to 5000°F Tests)
Strain Rate to YS - 0.05 in/min.

Strain Rate YS to UTS - 0.5 in/min.
Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Specimen Number	Test Temperature (°F)	Hold Time (min.)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BB-46	3500	3	0.0188	7.3	12.8	10.0	9.4	47.0
BB-47	3500	3	0.0191	7.6	14.3	18.0	8.5	42.0
BB-48	4000	3	0.0230	4.8	8.0	7.5 Failed outside gage length	-	52.0
BB-49	4000	3	-	Poor Temperature Control - No Test			-	-
BB-97	4500	3	0.0280	2.9	4.6	10.0	4.5	24.5
BB-103	4500	3	0.0280	1.9	3.5	16.0	4.3	23.0
BB-98	5000	3	0.0313	1.2	2.3	12.0	2.2	18.0
BB-105	4640	3	-	1.8	3.0	8.0	3.5	30.0

TABLE XXXIX

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot C

Test Condition 2

Machine - ETTM
Method Heating - Resistance
Hold Time at Temp. - 5 min. (1000 to 2000°F Tests), 3 min. (2500 to 5000°F Tests)
Strain Rate to Y.S. - 0.05 in/min.

Strain Rate Y.S. to U.T.S. - 0.5 in/min.
Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Specimen Number	Test Temperature (°F)	Hold Time (min.)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BC-7	R.T.	-	-	-*	164.5*	-	46.0	-
BC-8	R.T.	-	-	-*	200.0*	-	46.0	-
		*FTU at 0.05 in/min.						
BC-9	1000	5	0.0044	112.0	129.0	4.0	44.0	27.0
BC-10	1000	5	0.0047	107.0	124.0	4.5	41.0	34.0
BC-13	1500	5	0.0075	89.0	102.7	4.5	41.0	63.0
BC-14	1500	5	0.0075	99.7	108.5	4.5	39.5	43.0
BC-15	2000	5	0.0103	75.9	85.9	4.0	32.5	65.0
BC-16	2000	5	0.0105	80.0	88.8	4.0	34.5	65.0
BC-23	2500	3	0.0142	43.8	46.9	5.0	25.5	92.0
BC-24	2500	3	0.0136	44.9	47.6	5.0	27.7	92.0
BC-35	3000	3	0.0158	11.1	22.9	17.0	19.5	29.0
BC-36	3000	3	0.0156	11.0	21.1	17.0	15.6	28.0
BC-37	3500	3	0.0188	7.6	14.8	21.0	15.1	18.0
BC-38	3500	3	0.0188	7.5	14.9	24.0	15.5	10.0
BC-39	4000	3	0.0227	5.3	9.2	19.0	7.6	60.0
BC-40	4000	3	-	5.4	9.4	21.0	7.1	74.0
BC-41	4500	3	0.0274	2.7	4.3	11.0	3.3	70.0
BC-42	4500	3	0.0274	2.4	4.0	20.0	3.8	91.0
BC-120	5000	3	0.0272	1.5*	2.7	11.5	-	-
BC-121	5000	3	0.0276	2.4*	3.8	9.0	-	-
		*Extrapolated						

TABLE XXXX

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot A

Test Condition 3

Machine - ETTM
Method Heating - Resistance
Hold Time at Temperature - 30 minutes
Strain Rate to Y.S. - 0.005 in/min.
Strain Rate Y.S. to U.T.S. - 0.05 in/min.

Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Specimen Number	Test Temperature (°F)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BA-113	2000	0.0097	73.0	82.2	4.0	36.5	80
BA-18	2000	0.0099	58.8	62.0	4.0	29.0	--
BA-19	2000	0.0098	69.0	76.0	3.0	32.5	--
BA-110	2500	0.0128	12.6	23.8	15.0	31.5	92
BA-111	2500	0.0126	15.7	26.8	14.0	27.1	92
BA-112	2500	0.0128	19.0	27.0	12.0	25.5	91
BA-152	3000	Cracked Loading - No Test -			-	-	--
BA-153	3000	0.0162	10.0	17.8	17.0	20.2	76
BA-154	3000	0.0161	9.0	15.0	11.0	18.7	36
BA-149	3500	0.0194	6.2	9.8	15.0	13.0	48
BA-150	3500	0.0198	5.5	9.8	17.0	10.4	69
BA-151	3500	0.0196	5.9	10.6	17.0	12.5	47

TABLE XXXXI

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot B | **Test Condition 3**

Machine - ETTM
Method Heating - Resistance
Hold Time at Temperature - 30 minutes
Strain Rate to Y.S. - 0.005 in/min.
Strain Rate to Y.S. to U.T.S. - 0.05 in/min.

Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Specimen Number	Test Temperature (°F)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BB-30	2000	0.0095	84.0	92.0	4.0	33.0	51
BB-31	2000	0.0098	79.7	90.0	3.5	34.0	82
BB-32	2000	0.00975	74.5	82.5	4.5	34.0	88
BB-39	2500	0.0124	14.2	27.3	12.0	24.0	84
BB-40	2500	0.0124	13.6	24.8	15.0	22.5	89
BB-41	2500	0.0125	13.1	26.0	15.0	22.5	79

(TABLE XXXXI Continued on Next Page)

TABLE XXXXI (Continued)

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot B

Test Condition 3

Machine - ETTM
Method Heating - Resistance
Hold Time at Temp. - 30 minutes
Strain Rate to YS - 0.005 in/min.

Strain Rate YS to UTS - 0.05 in/min.
Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Specimen Number	Test Temperature (°F)	Hold Time (min.)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BB-42	3000	30	0.0151	9.1	16.5	13.0	14.5	69.0
BB-43	3000	30	0.0154	9.5	16.2	15.0	15.9	47.0
BB-45	3000	30	0.0158	8.2	15.0	15.0	16.0	52.0
BB-61	3500	30	0.0185	6.5	10.5	13.0	11.1	39.0
BB-62	3500	30	0.0190	7.5	11.8	15.0	10.6	34.0
BB-63	3500	30	0.0200	6.6	10.2	13.0	10.5	27.5

TABLE XXXXII

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot C | Test Condition 3

Machine	- ETTM	Atmosphere	- Argon-7% Hydrogen
Method Heating	- Resistance	Gage Length	- 2 inches
Hold Time at Temperature	- 30 minutes	Sheet Thickness	- 0.050 inch
Strain Rate to Y.S.	- 0.005 in/min.	Specimen Direction	- Longitudinal
Strain Rate Y.S. to U.T.S.	- 0.05 in/min.		

Specimen Number	Test Temperature (°F)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BC-25	2000	0.0105	70.0	78.3	4.0	33.0	91.0
BC-26	2000	0.0105	73.0	82.0	4.0	35.0	49.0
BC-27	2000	0.0104	70.0	79.5	5.0	35.0	75.0
BC-28	2500	0.0139	18.0	28.5	12.0	27.5	93.0
BC-29	2500	-	Heat Overshot	- No Test	-	-	92.0
BC-30	2500	0.0136	16.6	27.3	12.0	29.0	93.0
BC-53	3000	0.015	9.2	17.5	23.0	16.9	-
BC-54	3000	0.0156	8.5	15.7	23.0	15.5	-
BC-55	3000	-	-	-	-	-	-
BC-134	3500	0.0173	7.5	12.8	16.0	12.9	-
BC-135	3500	0.0187	6.9	11.8	15.0	11.8	-
BC-136	3500	0.0174	7.0	12.4	13.0	11.5	-

TABLE XXXXIII

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot A

Test Condition 4

Machine - ETTM
Method Heating - Resistance
Hold Time at Temperature - 30 minutes
Strain Rate to Y.S. - 0.05 in/min.
Strain Rate Y.S. to U.T.S. - 0.5 in/min.

Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Specimen Number	Test Temperature (°F)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BA-114	2500	0.0125	15.0	28.3	12.0	22.0	95
BA-115	2500	0.0128	15.0	27.1	14.0	22.3	95
BA-116	3000	0.0157	7.5	19.0	20.0	16.1	96
BA-117	3000	0.0162	11.2	21.2	18.0	18.0	95
BA-118	3500	0.0192	7.4	15.3	21.0	12.6	85
BA-119	3500	0.0194	6.7	13.9	29.0	12.6	83
BA-33	2000	0.0099	68.8	73.5	3.5	34.4	--
BA-34	2000	0.0103	61.0	64.1	4.0	32.7	--

TABLE XXXXIV

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot B

Test Condition 4

Machine - ETTM
Method Heating - Resistance
Hold Time at Temperature - 30 minutes
Strain Rate to Y.S. - 0.05 in/min.
Strain Rate Y.S. to U.T.S. - 0.5 in/min.

Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Specimen Number	Test Temperature (°F)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BB-28	2000	0.0094	84.1	87.3	3.5	36.2	54
BB-29	2000	0.0097	91.5	100.0	3.5	32.0	60
BB-35	2500	0.0119	21.5	32.0	8.0	23.1	85
BB-36	2500	0.0118	18.4	32.2	10.0	18.6	77
BB-37	3000	0.0157	9.5	19.8	25.0	15.1	77
BB-38	3000	0.0162	9.9	20.5	22.0	12.8	83
BB-53	3500	0.0187	6.1	12.9	8.0	11.5	36
BB-54	3500	0.0188	7.8	15.0	18.0	10.5	-

TABLE XXXXV

MECHANICAL PROPERTIES FOR
COMMERCIALLY PURE TUNGSTEN SHEET (FANSTEEL)

Powder Lot C

Test Condition 4

Machine - ETTM
Method Heating - Resistance
Hold Time At Temperature - 30 minutes
Strain Rate to Y.S. - 0.05 in/min.
Strain Rate Y.S. to U.T.S. - 0.5 in/min.

Atmosphere - Argon-7% Hydrogen
Gage Length - 2 inches
Sheet Thickness - 0.050 inch
Specimen Direction - Longitudinal

Specimen Number	Test Temperature (°F)	Thermal Expansion (in/in)	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elongation in 2 in. (%)	Modulus of Elasticity x 10^6 psi	Reduction of Area (%)
BC-31	2000	0.0106	77.2	87.0	4.0	38.0	55.0
BC-32	2000	0.0106	78.5	88.0	3.5	35.0	48.0
BC-33	2500	0.0138	20.0	32.3	12.0	27.0	93.0
BC-34	2500	0.0136	20.1	31.6	11.5	27.7	93.0
BC-51	3000	0.0153	10.5	22.6	22.0	15.3	-
BC-52	3000	0.0152	9.5	21.5	15.5	16.6	-
BC-113	3500	0.0178	8.0	16.9	18.5	13.4	-
BC-114	3500	0.0177	8.5	17.1	19.0	10.5	-

TABLE XXXXVI

CHEMICAL COMPOSITION

Element	Parts Per Million, ppm (by weight) Powder Lot A	B	C	Method Used
Oxygen	20.0	21.7	16.0	a
Hydrogen	0.3	0.6	1.0	a
Carbon	49.0	40.0	25.0	c
Nitrogen	5.0	11.0	11.0	b
Mn	<10.0	20.0	10.0	d
Co, Pb, Ni, Zn, Sr, P, Ta, Nb, Ga, Zr	Less than 100 ppm for all powder lots			d
Cd, Be, Fe, B, Si, Mg, Cr, Sn, Bi, Al, Mo, V, Ba, Ca, Au, Ti, Ag, Cu, Ge, Pt, Na, Li, K	Less than 10 ppm for all powder lots			d

a - Vacuum Fusion (National Research Corp., Cambridge, Mass.)

b - Micro - Kjeldahl (National Research Corp., Cambridge, Mass.)

c - Conductrometric (National Research Corp., Cambridge, Mass.)

d - Semi-Quantitative Spectrographic (The Marquardt Corporation)

APPENDIX

TUNGSTEN SHEET SPECIFICATION

HMS 6-1066

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	MATERIAL SPECIFICATION	NUMBER HMS 6-1066 ISSUED 5-4-61 REVISED 7-13-61

TITLE: COMMERCIALLY PURE TUNGSTEN SHEET

1. Acknowledgement. A vendor shall mention this specification in all quotations and when acknowledging purchase orders.

2. Form. .050 inch thick sheet, rolled from ingots which are pressed from powder and consolidated by sintering.

3. Application. For parts requiring exposure at high temperatures.

4. Composition.

Tungsten	Major
Molybdenum	0.10% max.
Iron	0.05% max.
Any other single element	0.01% max.

5. Condition

5.1 High degree of cold reduction

5.2 No stress relief heat treatment will be used.

5.3 Matte surface due to acid or caustic cleaning is acceptable.

5.4 Surface roughness as measured with a profilometer shall be less than 200 microinches.

6. Technical Requirements

6.1 Bend Ductility
A minimum of three bend angle test values shall be reported.

Specimen size	-	.050 x .500 x length as required
Stress direction	-	parallel to rolling direction
Bend radius	-	.062 inches
Ram deflection rate	-	0.5 inches/min. (approximate)
Test temperature	-	350°F (+0°, -20°)
Bend angle	-	80° minimum

6.2 Hardness
A minimum of five test values on Rockwell Superficial Hardness Scale 45-N shall be reported. No single value shall be less than 46.0 and the average shall be 48.0 or greater.

6.3 Microstructure
A highly elongated structure as shown in Figure 52 is desired. The minimum acceptable is shown in Figure 53, and Figure 54 is an example of unacceptable structure.

7. Quality

7.1 Material shall be uniform in quality and condition, clean, sound and free from internal and external imperfections.

7.2 Internal defect area revealed by ultrasonic inspection shall not exceed 1% of the surface area; excluding defects occurring within 1/8 inch of the sheet edge. Edge cracks shall not extend further than 1/8 inch into the sheet.

7.3 Flatness - sheet shall be flat within 1% of the distance between contact points of a straight edge laid in any direction upon the material. The amount of variation shall be determined by measuring the distance from the straight edge to the material at the point of greatest deviation. Figure 55 illustrates the method of measurement.

8. Tolerances

Thickness	$\pm$ .004 inches
Width	$\pm$ .060 inches
Length	$\pm$ .060 inches

9. Identification

Material shall be marked with manufacturer's identification and manufacturer's powder lot number.

10. Rejection

Material not conforming to this specification or to authorized modifications will be subject to rejection.

HMS-6-1066
5-4-61
7-13-61

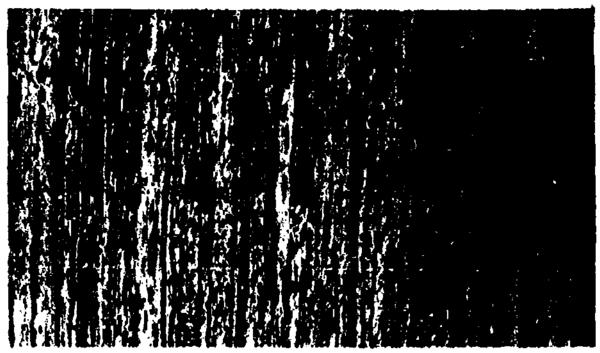
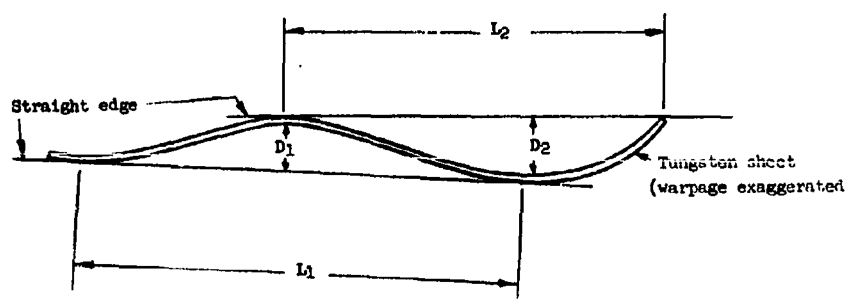


Figure 34 Desired Microstructure. 200 X. Murikami's Etch. Longitudinal Section.

Figure 35 Minimum Acceptable Microstructure. 200 X. Murikami's Etch. Longitudinal Section.

Figure 36 Unacceptable Micrcstructure. 200 X. Murikami's Etch. Longitudinal Section.



$\frac{D}{L}$ shall not be greater than .01

Figure 37. Measurement of Flatness